

GEORGIA DOT RESEARCH PROJECT 15-11

FINAL REPORT

**IMPLEMENTATION OF AUTOMATIC SIGN INVENTORY
AND PAVEMENT CONDITION EVALUATION ON
GEORGIA'S INTERSTATE HIGHWAYS**



**OFFICE OF RESEARCH
15 KENNDY DRIVE
FOREST PARK, GA 30297-2534**

Contract Research

GDOT Research Project No. 15-11

Final Report

**IMPLEMENTATION OF AUTOMATIC SIGN INVENTORY AND
PAVEMENT CONDITION EVALUATION ON GEORGIA'S INTERSTATE
HIGHWAYS**

By

Yichang (James) Tsai, Ph.D., P.E.

Zhaohua Wang, Ph.D., P.E.

Chengbo Ai, Ph.D.

Georgia Institute of Technology

Contract with

Georgia Department of Transportation

In cooperation with

U.S. Department of Transportation

Federal Highway Administration

February 2017

The contents of this report reflect the views of the author(s) who is (are) responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Georgia Department of Transportation or of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

1. Report No.: FHWA-GA-16-15-11	2. Government Accession No.:	3. Recipient's Catalog No.:	
4. Title and Subtitle: Implementation of Automatic Sign Inventory and Pavement Condition Evaluation on Georgia's Interstate Highways		5. Report Date: February 2017	
		6. Performing Organization Code:	
7. Author(s): Yichang (James) Tsai; Zhaohua Wang; Chengbo Ai		8. Performing Organ. Report No.: 15-11	
9. Performing Organization Name and Address: Georgia Institute of Technology 790 Atlantic Drive Atlanta, GA 30332-0355		10. Work Unit No.:	
		11. Contract or Grant No.: 0013245	
12. Sponsoring Agency Name and Address: Georgia Department of Transportation Office of Research 15 Kennedy Drive Forest Park, GA 30297-2534		13. Type of Report and Period Covered: Final; June 2, 2015 - September 2, 2016	
		14. Sponsoring Agency Code:	
15. Supplementary Notes:			
16. Abstract: Traffic signs and pavements are indispensable assets to facilitate safe and uninterrupted travel. Manual methods are used for both traffic sign inventory and pavement condition evaluation by the Georgia Department of Transportation (GDOT), although they take excessive time, consume great amounts of labor, and sometimes expose field engineers to roadway hazards. GDOT still lacks a complete traffic sign inventory for its interstate highway system. For pavement condition evaluation, although the current Pavement Condition Evaluation System (PACES) performs well on non-interstate roadways, it is challenging to survey interstate highways due to limited parking space and safety concern caused by high-speed, high-volume traffic. To leverage the automated methods developed through its national demonstration project, the Georgia Tech research team surveyed more than 2,500-survey-mile interstate highways in Georgia and established a complete traffic sign inventory and Computerized PACES (COPSACE) database using the newly proposed streamlined procedures. The successful implementation has demonstrated that the streamlined procedures provide a consistent, reliable, and cost-effective means for traffic sign inventory and pavement condition evaluation.			
17. Key Words: Interstate; Sign Inventory; PACES; Image; Mobile LiDAR; 3D Laser		18. Distribution Statement: No Restriction	
19. Security Classification (of this report): Unclassified	20. Security classification (of this page): Unclassified	21. Number of Pages: 63	22. Price:

TABLE OF CONTENTS

TABLE OF CONTENTS	ii
LIST OF TABLES	iv
LIST OF FIGURES	vi
ACKNOWLEDGEMENTS	viii
EXECUTIVE SUMMARY	x
CHAPTER 1. INTRODUCTION	1
1.1. Research Background and Research Need	1
1.2. Research Objectives	3
1.3. Report Organization	4
CHAPTER 2. OVERVIEW OF THE SENSING DATA COLLECTION	5
2.1. Georgia Tech Sensing Vehicle (GTSV)	5
2.2. Interstate Highway System in Georgia	8
CHAPTER 3. DATA PROCESSING FOR TRAFFIC SIGN INVENTORY	1
3.1. Key Characteristics of Traffic Signs	1
3.2. Streamlined Procedure	4
3.3. Results	5
CHAPTER 4. DATA PROCESSING FOR PAVEMENT CONDITION EVALUATION	11
4.1. Distresses Defined in PACES	11

4.2. Streamlined Procedure	13
4.3. Results	18
CHAPTER 5. BENEFITS OF THE STREAMLINED PROCEDURES	21
5.1. Benefits of Streamlined Traffic Sign Inventory	21
5.2. Benefits of Streamlined Pavement Condition Evaluation	22
CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS	29
REFERENCES	34

LIST OF TABLES

Table 3.1 Detailed statistics of traffic signs in poor conditions on each interstate highway	6
Table 3.2 Detailed statistics of overhead traffic signs on each interstate highway.....	7
Table 3.3 Detailed numbers of traffic signs in each working district	8
Table 3.4 Detailed statistics of traffic signs in poor conditions in each working district ..	9
Table 3.5 Detailed statistics of overhead traffic signs in each working district	10
Table 4.1 Asphalt pavement distresses defined in COPACES	12

LIST OF FIGURES

Figure 2.1 Mobile imaging sub-system on GTSV6

Figure 2.2 Illustration of the collected sensing data using the mobile imaging sub-system
.....7

Figure 2.3 Components of 3D Line Laser System Integrated on the GTSV8

Figure 2.4 Illustration of the collected data using the 3D line laser sub-system.....8

Figure 2.5 Spatial locations and extents of these interstate highways in Georgia9

Figure 3.1 Examples of four categories of poor sign conditions2

Figure 3.2 Example of overhead sign failure (FHWA, 2013)3

Figure 3.3 Examples of the overhead sign categories defined by GDOT3

Figure 3.4 Flowchart of the proposed streamlined traffic sign inventory procedure.....4

Figure 3.5 Distribution of traffic sign classifications on interstate highways in Georgia ..5

Figure 3.6 Traffic signs with poor conditions on interstate highways in Georgia6

Figure 3.7 Traffic signs installed on overhead structure on interstate highways in Georgia
.....7

Figure 3.8 Distribution of the interstate traffic signs in the 7 working districts8

Figure 3.9 Distribution of traffic sign in poor condition in the 7 working districts9

Figure 3.10 Distribution of the overhead traffic signs in the 7 working districts..... 10

Figure 4.1 Flowchart of the proposed streamlined sign data collection procedure..... 14

Figure 4.2 Illustration of the fifty-two 100-foot sections reported within a 1-mile segment
..... 16

Figure 4.3 Locations and extents of the interstate highways with asphalt surface 17

Figure 4.4 Derived COPACES ratings using the proposed method 19

Figure 4.5 Distribution of the deducts from the different pavement distresses 20

Figure 5.1 The PDA used in GDOT and field operation in GDOT 21

Figure 5.2 Sample segment on I-75 NB with different deducts from load cracking and
block cracking 24

Figure 5.3 Distribution of the load cracking and block cracking in Segment #248 25

Figure 5.4 Raveling extent difference in all of the 1-mile segments covering interstate
highways in Georgia 26

Figure 5.5 Sample images for Segment #811 on I-75 SB 27

ACKNOWLEDGEMENTS

The work described in this final report was supported by the Georgia Department of Transportation (GDOT) research project 15-11. We would like to thank the following personnel in GDOT: Ms. Meg Pirkle (Chief Engineer), Ms. Angela Alexander (Organizational Performance Management Director), Mr. David Jared and Mr. Binh Bui from the Office of Research; Mr. Dale Brantley, Ms. Ernay Robinson, Mr. Larry Barnes, Mr. Michael Keene, Mr. David Sparks, Mr. Sam Wheeler, and Mr. Thomas Mims (retired) from the Office of Maintenance, for their strong support and heavy involvement. We would like to thank the support provided by the following research projects: NCHRP IDEA-121, “Using Image Pattern Recognition Algorithms for Processing Video Log Images to Enhance Roadway Infrastructure Data Collection,” NCHRP IDEA-163, “Development of an Asphalt Raveling Detection Algorithm Using Emerging 3D Laser Technology and Macrottexture Analysis,” and USDOT “Remote Sensing and GIS-enabled Asset Management System (RS-GAMS)”, that established a solid foundation to make this large-scale implementation of automatic and streamlined sign inventory and asphalt pavement condition evaluation possible. We would also like to thank the members of the research team at the Georgia Institute of Technology (Georgia Tech), including Dr. Chenglong Jiang, Mr. Bruno Pop-Stefanov, Mr. Yipu Zhao, Ms. Josephine M Simon, Mr. Geoffrey Price, Mr. Anirban Chatterjee, and Ms. Yiching Wu, for their diligent work.

EXECUTIVE SUMMARY

Traffic signs and pavements are indispensable assets to facilitate safe and uninterrupted travel. Manual methods have been used for both traffic sign inventory and pavement condition evaluation by the Georgia Department of Transportation (GDOT), although they take excessive amounts of time, consume great amounts of labor, and sometimes expose field engineers to roadway hazards. GDOT still lacks a complete traffic sign inventory for interstate highway system in Georgia. For pavement condition evaluation, although the current Pavement Condition Evaluation System (PACES) performs well on non-interstate roadways, it is challenging to survey interstate highways due to limited parking space and safety concern caused by high-speed, high-volume traffic. To leverage the automated algorithms and methods developed through its national demonstration project, the Georgia Tech research team surveyed more than 2,500-survey-mile interstate highways in Georgia and established a complete traffic sign inventory and asphalt pavement condition evaluation using the proposed streamlined procedures. The successful implementation demonstrates that the streamlined procedures provide a consistent, reliable, and cost-effective means for traffic sign inventory and pavement condition evaluation on interstate highways. The following summarize the major outcomes:

1. 22,344 traffic signs were inventoried along all the interstate highways in Georgia. The majority of the signs are guide signs that make up 62.0% (13,857 signs) of the total population. The rest of the population consists of 3,692 regulatory signs, 3,209

warning signs, 1,490 other signs (customized signs in Georgia), and 96 temporary signs.

- There are **897** signs (4.0% of the overall traffic sign population) in poor condition that require sign maintenance actions, including the following:
 - 1) Surface failure (390 signs, 43.5%)
 - 2) Dirty (263 signs, 29.3%)
 - 3) Post failure (123 signs, 13.7%)
 - 4) Obstructed (121 signs, 13.5%)

- There are **4,414** overhead signs (19.8% of the overall traffic sign population). They have a high potential risk and require frequent monitoring and condition assessment. They are divided into four categories and inventoried with their locations (latitude and longitude coordinates).
 - 1) Sign-Bridge (1,831 signs, 41.5%)
 - 2) Bridge-Mounted (1,476 signs, 33.4%)
 - 3) Cantilever (504 signs 11.4%)
 - 4) Butterfly (603 signs, 13.7%)

- Through processing the large-scale dataset collected on the interstate highways in Georgia, the productivity of sign inventory has been significantly improved by employing the streamlined traffic sign inventory procedure using sensing data. It was estimated that an average of 13 min/mile (1.5 min/sign, on average 8 signs/mile on interstate highways in Georgia) might be achieved for traffic sign inventory using the proposed procedures, which is 1~1.5 times faster than the average 25~30 min/mile (3~4 min/sign) using manual method. In addition, the

safety improvement and the reduction of survey vehicles' stop-and-go fuel consumption are, potentially, significant, especially for interstate highways.

2. **1,513** miles of Computerized PACES (COPACES) segments were rated using the streamlined pavement condition evaluation procedure and the sensing data. The results cover the full length of the interstate highways with an asphalt surface, including 1,434 segments surveyed in the FY2015 COPACES database and 79 unsurveyed segments. The segment results were further aggregated into 316 COPACES projects, including 302 projects from the FY2015 COPACES database and 14 unsurveyed projects. The COPACES ratings derived from the streamlined pavement condition evaluation procedure and the COPACES ratings surveyed by field engineers in GDOT show very similar trends. The following observations are made through the comparison of two selected cases that were surveyed by GDOT using the conventional method:
 - Some of the selected “representative” sections may be biased due to the practical challenges encountered by field engineers during interstate data collection, e.g., available shoulder parking spaces. On the contrary, since the streamlined procedure extracts full-coverage crack data and then select a 100-ft section based on a consistent 60 percentile deduct for each 1-mile segment, the results could well capture the “representativeness” of the section for the corresponding 1-mile segment.
 - The manual survey conducted by field engineers may overlook or underestimate the severity and extent of raveling due to the nature of windshield surveys, especially when the road is not continuously raveled. However, since the

streamlined procedure continuously identifies and classifies raveling for the full coverage of the roadway, it can capture the overall raveling condition without overlooking isolated raveled segments.

This study demonstrates that the proposed streamlined procedures provide a consistent, reliable, and cost-effective means for traffic sign inventory and pavement condition evaluation, especially on interstate highways. Through its processing of the large-scale dataset collected on the interstate highways in Georgia, the Georgia Tech research team has observed significant improvement in productivity by employing the streamlined procedures for traffic sign inventory and pavement condition evaluation using sensing data. Thus, it is recommended to employ and improve the streamlined procedures to sustain a long-term interstate highway inventory and condition evaluation program. In addition, the developed procedures will also enable GDOT to cost-effectively extract COPACES data using the 3D laser data to be collected in the future by vendors with a proper data collection specification. In addition, to leverage mobile light detection and ranging (LiDAR) data collection, it is also recommended to evaluate the feasibility of using mobile LiDAR for a large-scale, automatic traffic sign retroreflectivity condition assessment.

CHAPTER 1. INTRODUCTION

1.1. Research Background and Research Need

Traffic signs are important for roadway safety and provide critical guidance to road users with traffic regulation, road hazard warnings, destination information, and other geographic information. Because of the vital role that traffic signs play in roadway safety and information conveyance, the Federal Highway Administration (FHWA) outlines the detailed standards and regulations for traffic signs in the Manual on Uniform Traffic Control Devices (MUTCD). The MUTCD details the specific physical characteristics by which regulatory, warning, and guide signs must abide, including location, geometry, color, icon and wording, condition, etc. Through traffic sign data collection programs, transportation agencies can acquire critical traffic sign information to evaluate the performance and lifespan of traffic signs better and to generate maintenance and funding strategies more effectively. However, most of the inspection programs carried out by transportation agencies are manual methods, which require field engineers to physically inspect and record the information of each individual traffic sign; these inspections take excessive amounts of time, consume great amounts of labor, and sometimes expose field engineers to roadway hazards. Thus, these manual methods are practically prohibitive for network-level traffic sign inventory in large transportation agencies, e.g. the state departments of transportation (DOTs) who manage millions of traffic signs. This situation applies to the Georgia Department of Transportation (GDOT) as well. Although GDOT has a handheld-based data collection method for traffic sign inventory and condition evaluation, the method requires significant amounts of labor, equipment, and time, and it is hazardous to the field engineers when data collection is conducted near high-speed, high-volume traffic. GDOT currently does not have

a complete sign inventory. Therefore, GDOT needs a safer and more cost-effective means to collect traffic sign data, especially on high-speed, high-volume interstate highways.

Pavements are one of the most critical infrastructures for providing safe, uninterrupted, and comfortable travel for drivers to reach their destinations. As one of the most invested infrastructures in many public transportation agencies, GDOT critically needs pavement surface distress data to monitor its statewide pavement conditions, identify maintenance activities, and optimally allocate pavement funds. In GDOT, the Office of Maintenance (OM) collects the statewide pavement condition data annually (it has been changed to conduct pavement condition survey biennially since 2015) based on the distress protocol defined in GDOT's Pavement Condition Evaluation System (PACES). Currently, GDOT has accumulated about 30 years of PACES data for its statewide pavements; this data is the key component used by OM to perform statewide pavement maintenance, and the Georgia Asset Management System (GAMS) utilizes the data, too. The current manual method works well on state-maintained, non-interstate roadways, but it is difficult and, sometimes, prohibitive for surveying interstate highways due to the safety concerns caused by limited parking areas for field engineers and high-speed, high-volume traffic. Therefore, GDOT needs a safer and more cost-effective method to complement its manual method of data collection, especially on interstate highways.

In the national demonstration project performed by Georgia Tech research team, streamlined traffic sign inventory and pavement condition evaluation procedures have been proposed. In these streamlined procedures, automatic traffic sign detection using mobile light detection and ranging (LiDAR), video log image data, and automatic pavement distress detection and classification methods, including cracking, rutting, raveling, etc., using emerging 3D line laser

imaging technology has been incorporated to enhance inventory data quality and productivity. The proposed procedures and the developed methods for traffic sign and pavement surface condition data collection have been validated on I-285. Based on the discussions with OM and the Office of Research (OR), all interstate highways in Georgia are selected for this large-scale case study because interstate highways are the major capital investments. The collected traffic sign data can be input into GDOT's current asset management system, while the pavement condition data will be stored in GDOT's Computerized PACES (COPACES) database and can be further used and/or integrated with GAMS.

1.2. Research Objectives

The objectives of this research project focusing on the interstate highways maintained by GDOT (more than 2,500 survey miles) are 1) to comprehensively collect traffic sign and pavement condition data, 2) to validate the performance of the automatic traffic sign inventory and the automatic pavement distress detection and classification method, and 3) to validate the streamlined data collection procedures for traffic sign inventory and pavement condition. The traffic sign inventory includes sign locations, sign types, MUTCD codes, and traffic sign conditions based on the Signs Chapter of GDOT's Foremans Academy (2008). Pavement condition data includes ten types of pavement distresses that are defined in the PACES manual (2007).

After the automatic methods and streamlined data collection procedures are successfully implemented on interstate highways, they can be further extended to all other state routes maintained by GDOT. The results from this study will be valuable to GDOT and to other public

transportation agencies that are maintaining large-scale roadway networks, including local agencies, other state DOTs, and the FHWA. The major tasks include the following:

- Using Georgia Tech Sensing Vehicle (GTSV) to collect sensing data (video log images, LIDAR point cloud, and 3D laser data) on the entire Georgia's interstate highway system;
- Conducting traffic sign inventory data collection using video log images and mobile LiDAR data;
- Conducting pavement condition data collection using 3D laser data;
- Summarizing research findings.

1.3. Report Organization

This report is organized as follows. CHAPTER 1 presents the background and objective of the study. CHAPTER 2 overviews the sensing data collection conducted in this study on the interstate highway system in Georgia. CHAPTER 3 presents the data collection and processing methods employed in this study for traffic sign inventory and the corresponding results.

CHAPTER 4 presents the data collection and data processing methods employed in this study for pavement condition evaluation and the corresponding results. CHAPTER 5 discusses the benefits of employing sensing-based methods and streamlined procedures for both traffic sign inventory and pavement distress identification. CHAPTER 6 summarizes the findings and suggests recommendations for the future implementation for GDOT.

CHAPTER 2. OVERVIEW OF THE SENSING DATA COLLECTION

2.1. Georgia Tech Sensing Vehicle (GTSV)

The GTSV, originally integrated into the national demonstration project performed by the Georgia Tech research team, is introduced in the data collection in this study. Two major subsystems were integrated into the GTSV, including the mobile imaging sub-system for traffic sign inventory and the 3D line laser sub-system for the pavement condition data collection.

The mobile imaging sub-system used in this project consists of three primary components, including the LiDAR sensor, the precise positioning system, and the camera system. The LiDAR sensor is used to acquire the point cloud of the target, e.g. a traffic sign. Each point includes the accurate distance from the sensor to the target, the relative angle of the laser beam with respect to the LiDAR sensor, and the corresponding reflectance intensity. The precise positioning system is used to acquire accurate global positioning system (GPS) coordinates and poses for the LiDAR sensor. Thus, the GPS coordinates of each point from the LiDAR sensor can be derived. The positioning system is composed of a GPS, an inertial measurement unit (IMU), and a distance measurement instrument (DMI) to acquire the precise GPS coordinates. The camera system is synchronized with the LiDAR sensor to provide corresponding color images. FIGURE 2-1 illustrates the mobile imaging sub-system on the GTSV.



FIGURE 2-1

Mobile imaging sub-system on GTSV

The current LiDAR sensor can produce 10,000 laser points per second. As the vehicle moves in the longitudinal direction, the scanning line of the LiDAR system is aligned perpendicularly to the ground. The scanning range is $\pm 40^\circ$ to the horizontal direction, which produces an 80° fan covering the roadside. For example, if a standard 48 in. \times 60 in. speed limit sign is mounted on the roadside with a lateral offset of 12 ft. to the edge of the road, the current configuration will be able to acquire a point cloud containing approximately 12×8 points at 60 mph (100 km/h). Based on the previous study, the frequency of the LiDAR system is configured at 100 Hz and 100 points within each scan, while the LiDAR heading angle is configured at 20° . Such a configuration was carefully recommended in the previous study for better acquiring the traffic sign data (Ai and Tsai, 2015). The three video cameras (i.e., front right, front center, and front left camera) are synchronized and calibrated with the LiDAR sensor so that the corresponding 2-D images can be integrated with the 3D LiDAR point cloud in the same location-referencing coordinates. The data collection interval of 5 meters is used for collecting the video log images, as recommended in the previous study for optimizing the data storage with sufficient overlap in the video log image sequence (Ai and Tsai, 2015). FIGURE 2-2 shows an illustration of the collected sensing data using the mobile imaging sub-system.

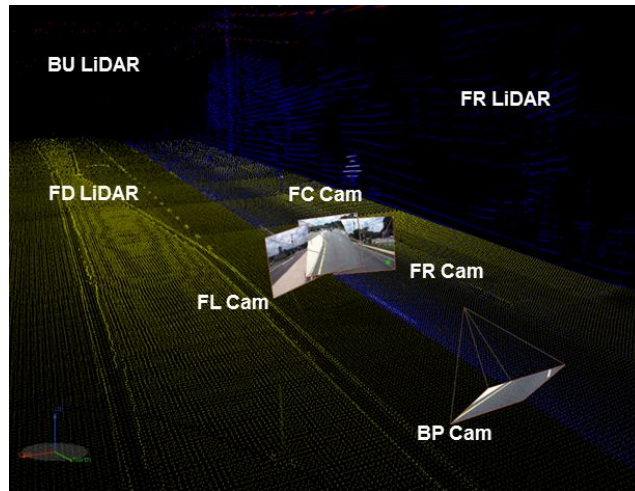


FIGURE 2-2

Illustration of the collected sensing data using the mobile imaging sub-system

The 3D line laser consists of three primary components, including the imaging component, the distance-measuring component, and the data processing component. The imaging component is used to capture the pavement texture data using external infrared laser illumination and the spatial high-intensity camera. This component consists of two separate laser sensors to cover a full-lane width. Each laser sensor includes a dedicated infrared laser illumination and a high-intensity, area-scanning camera. The distance-measuring component provides a data-capturing signal by using a DMI, which is user-customizable. The data processing component computes the captured data into 3D range results using a high-performance workstation. As shown in FIGURE 2-3, the two laser sensors are installed on each side of the roof at the back of the GTSV. The current sensor delivers a resolution of 5 mm in the longitudinal direction and 1 mm in the transversal direction, with a resolution of 0.5 mm in the vertical direction. The field of view of the two sensors covers a full-lane width, i.e. 4 m. The research team configured both sensors at approximately 15 degrees clockwise to the transverse direction to avoid overlooking transverse cracks in the pavement. During data collection, each laser sensor uses a high-powered laser line

projector with a customized filter to generate a fine infrared laser line illuminating a strip of the pavement. The corresponding spatial high-intensity camera captures the deformed laser line on the pavement. From the captured image, range measurements are extracted (Tsai and Wang, 2013). FIGURE 2-4 illustrates the collected data using the 3D line laser sub-system.

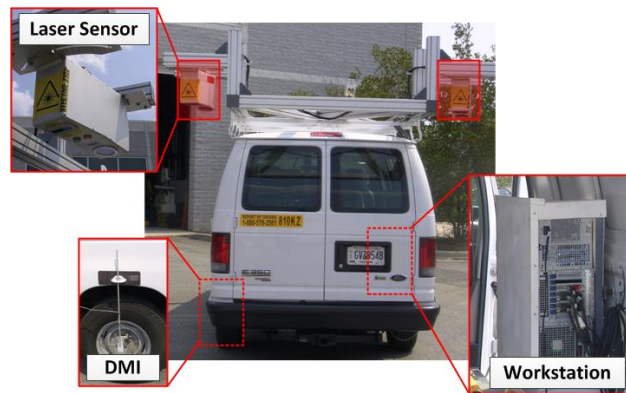


FIGURE 2-3

Components of 3D Line Laser System Integrated on the GTSV



FIGURE 2-4

Illustration of the collected data using the 3D line laser sub-system

2.2. Interstate Highway System in Georgia

The interstate highways in Georgia comprise seven primary interstate highways, including Interstate 75 (Route No: 0401), Interstate 20 (Route No: 0402), Interstate 85 (Route No: 0403), Interstate 16 (Route No: 0404), Interstate 95 (Route No: 0405), Interstate 59 (Route No: 0406),

and Interstate 24 (Route No: 0409), and eight auxiliary interstate, including Interstate 285 (Route No: 0407), Interstate 475 (Route No: 0408), Interstate 185 (Route No: 0411), Interstate 675 (Route No: 0413), Interstate 520 (Route No: 0415), Interstate 575 (Route No: 0417), Interstate 985 (Route No: 0419), and Interstate 516 (Route No: 0421). The total survey length of the interstate highway in Georgia covers 2,541.4 miles. FIGURE 2-5 shows the spatial locations and extents of these interstate highways.

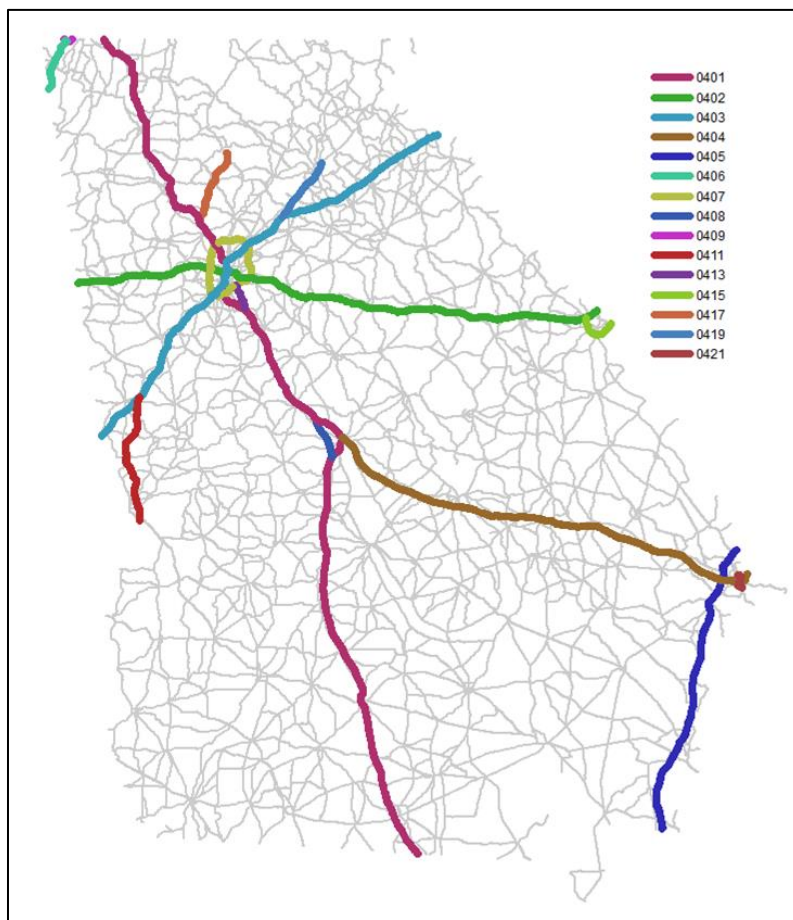


FIGURE 2-5
Spatial locations and extents of these interstate highways in Georgia

CHAPTER 3. DATA PROCESSING FOR TRAFFIC SIGN INVENTORY

3.1. Key Characteristics of Traffic Signs

This chapter defines the main traffic sign characteristics that were collected. The operation of traffic sign data collection includes two primary steps, inventory and condition assessment. Inventory collects sign locations and attributes, e.g. classification of traffic signs, while condition assessment determines the performance adequacy of inventoried signs. Within these steps, location, classification, and conditions are identified as the key characteristics that are required in the operation of traffic sign data collection.

Sign Location: Traffic sign location is defined by GPS coordinates (i.e. longitude, latitude) that can uniquely define the spatial position. Extracting the location for each individual sign is the most important step for traffic sign inventory. In this study, WGS84 geodetic GPS coordinates are used to represent the traffic sign location, which can be flexibly converted to a linear referencing system that is used in GDOT.

Sign Classification: Traffic sign classification is defined as the traffic sign classes that can distinguish different traffic sign functionalities, which lead to different designs, e.g. RX-X as regulatory signs, WX-X as warning signs, etc. (note: X is a number.). There are more than 670 types of traffic signs defined in the MUTCD that belong to three classifications: regulatory, warning, and guide. In addition, there could be some sign types that only occur within certain states or regions, and are assigned with internal

MUTCD codes. In this research project, the Signs Chapter of GDOT's Foremans Academy (2008) is used to define the sign classification and details the general MUTCD code and the internal MUTCD code.

Sign Condition: Traffic sign condition is represented by the visual defects and the retroreflectivity. In this study, daytime inspection using video log images is the focus that identifies visual defects; studying the retroreflectivity condition, which is covered by nighttime inspection, is not in the scope of this research project, and recommended for future research. Four categories of poor sign conditions are defined in this study, including post failure, dirty, obstruction, and surface failure. Based on the Signs Chapter of GDOT's Foreman's Academy (2008), the four categories of poor sign conditions correspond to four maintenance actions defined by Highway Maintenance Management System (HMMS) (Hensing and Rowshan, 2005), including straightening, cleaning, vegetation trimming, and replacing. FIGURE 3-1 shows several examples of signs in poor condition in each category.



FIGURE 3-1

Examples of four categories of poor sign conditions

Overhead Sign: Besides the above-mentioned three traffic sign characteristics, overhead signs are specially considered and separated from ground-mounted traffic signs.

Although overhead signs only contribute a small portion of the entire sign population, the

damage of these signs and/or their corresponding support, e.g. panel failure, support structure failure, etc., may potentially lead to serious hazards to road users. FIGURE 3-2 shows an example of such hazardous situations.



FIGURE 3-2
Example of overhead sign failure (FHWA, 2013)

Therefore, overhead signs are specially categorized and inventoried in detail. According to the different supporting structures for overhead signs defined in the Signs Chapter of GDOT's Foreman's Academy (2008), three categories are inventoried, including Sign-Bridge-Mounted, Cantilever-Mounted, and Bridge-Mounted and Butterfly-Mounted traffic signs. FIGURE 3-3 illustrates these three categories. Inventorying the detailed categories of overhead signs and identifying the spatial locations of these signs will be beneficial to the subsequent maintenance and/or more detailed structure inspection.



FIGURE 3-3
Examples of the overhead sign categories defined by GDOT

3.2. Streamlined Procedure

In this study, a streamlined procedure for sign data collection that aims to improve the data quality and productivity of the data collection practice while keeping field engineers from being exposed to roadway hazards was applied. The procedure utilizes both the available automatic method for traffic sign detection and several customized interactive tools for traffic sign recognition and the extraction of other characteristics. FIGURE 3-4 shows the flowchart of the proposed procedure, which consists of five primary steps. The quality assurance and quality control (QA/QC) steps are used to guarantee the quality of the results.

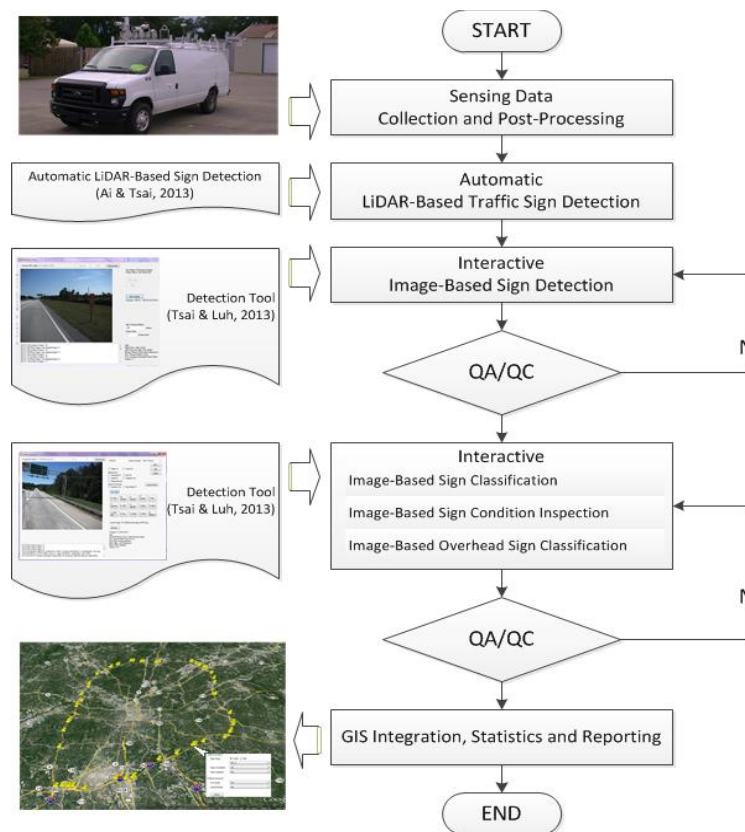


FIGURE 3-4

**Flowchart of the proposed streamlined traffic sign inventory procedure
(Ai and Tsai, 2015; Luh and Tsai, 2012; Tsai, 2009; Tsai and Wang, 2013)**

3.3. Results

In this study, there are 22,344 traffic signs that are inventoried through the proposed approach. Among all the identified signs, the majority of the signs are guide signs that make up 62.0% of the total population (13,857 signs). The rest of the population consists of 3,692 regulatory signs, 3,209 warning signs, 1,490 other signs (customized signs in Georgia), and 96 temporary signs. FIGURE 3-5 shows the distribution of the traffic signs on the interstate highways in Georgia based on their classifications.

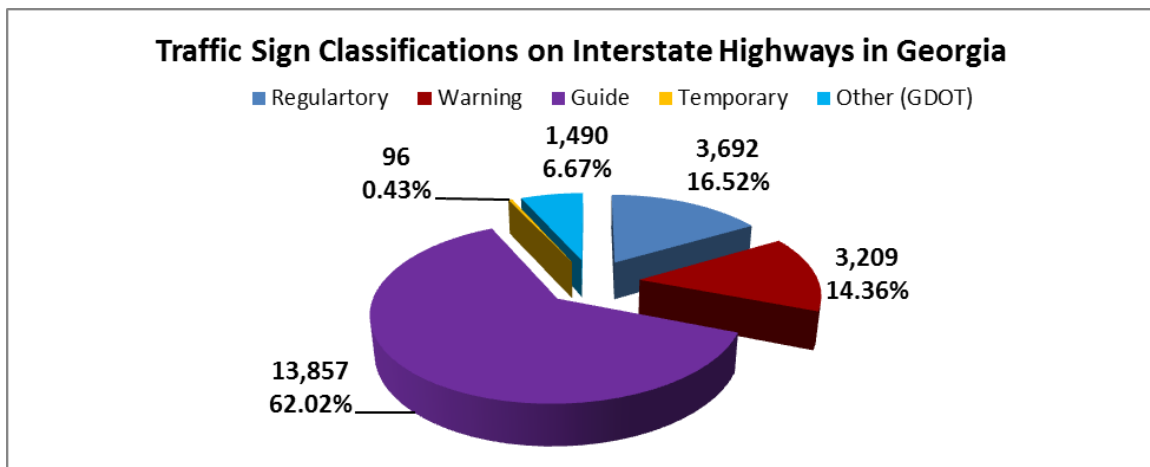


FIGURE 3-5

Distribution of traffic sign classifications on interstate highways in Georgia

Among all the identified signs, 4.0% of the signs (i.e. 897 signs) are in poor condition to different extents as defined in the Signs Chapter of GDOT's Foremans Academy (2008). Among all the signs in poor conditions, surface failure (390 signs, 43.5%) and being dirty (263 signs, 29.3%) are the two primary reasons for poor conditions. The rest of the signs are in poor condition due to having a failed post (123 signs, 13.7%) and being obstructed (121 signs, 13.5%). Overall, the number of traffic signs in poor conditions is only a small portion of the total number of traffic signs, indicating overall, well-maintained sign

condition in GDOT. FIGURE 3-6 shows the distribution of the traffic signs in poor condition on the interstates. TABLE 3-1 shows the detailed statistics for each interstate highway in Georgia.

TABLE 3-1

Detailed statistics of traffic signs in poor conditions on each interstate highway

	I-75	I-20	I-85	I-16	I-95	I-59	I-285	I-475	I-24	I-185	I-675	I-520	I-575	I-985	I-516	Total
Surface Failure	109	63	48	31	16	8	29	5	2	11	6	12	24	20	6	390
Post Failure	56	14	9	10	10	0	9	0	1	3	3	1	7	0	0	123
Dirty	56	21	19	23	27	10	18	1	13	11	8	0	36	20	0	263
Obstructed	45	23	13	4	6	0	22	0	1	3	2	1	1	0	0	121
Total	266	121	89	68	59	18	78	6	17	28	19	14	68	40	6	897

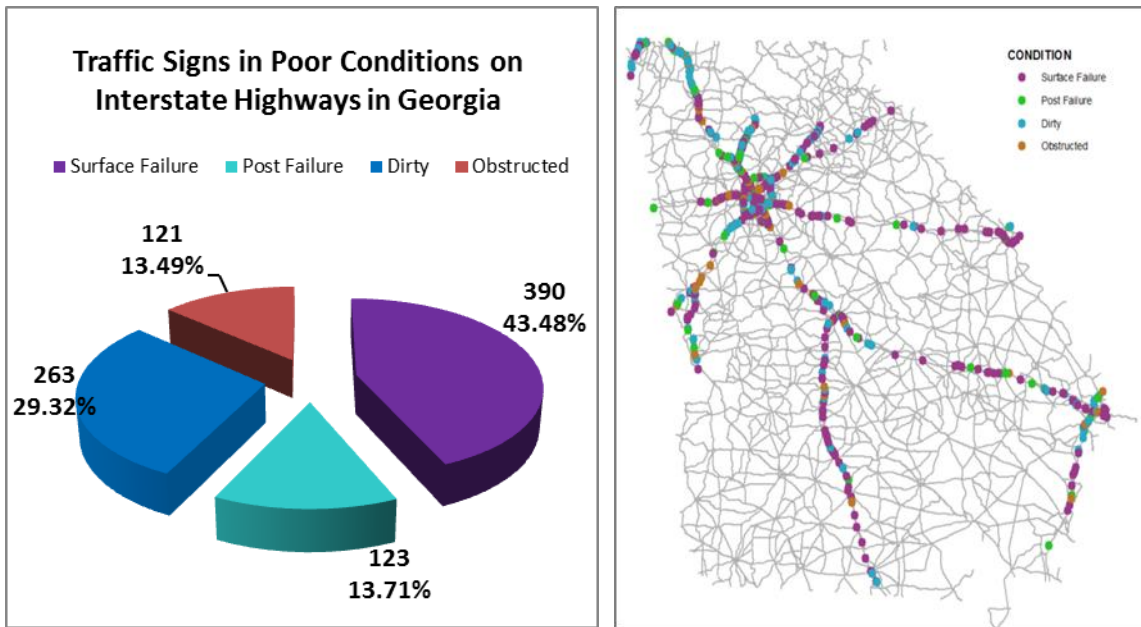


FIGURE 3-6

Traffic signs with poor conditions on interstate highways in Georgia

Among all the inventoried signs, 19.8% of the signs (i.e. 4,414 signs) are installed on overhead structures (Sign-Bridge, Cantilever, Bridge and Butterfly signs). About 41.5% of the overhead signs (i.e., 1,831 signs) are installed on sign-bridges, while 33.4% of the overhead signs are installed on bridges or other permanent overhead structures (i.e., 1,476

signs). The rest of the overhead signs are installed either on cantilever structures (11.4%, 504 signs) or butterfly structures (13.7%, 603 signs). FIGURE 3-7 shows the distribution of the overhead signs on the interstate highways in Georgia based on their base supporting structures. TABLE 3-2 shows the detailed statistics for each interstate highway in Georgia.

TABLE 3-2
Detailed statistics of overhead traffic signs on each interstate highway

	I-75	I-20	I-85	I-16	I-95	I-59	I-285	I-475	I-24	I-185	I-675	I-520	I-575	I-985	I-516	Total
Sign-Bridge Mounted	560	277	421	23	82	4	274	28	14	45	14	29	27	21	12	1,831
Cantilever Mounted	220	105	86	0	39	0	31	0	0	13	3	4	2	1	0	504
Butterfly Mounted	270	74	81	1	43	0	45	26	0	16	2	3	2	40	0	603
Bridge Mounted	479	305	197	80	68	10	189	12	2	47	16	14	38	18	1	1,476
Total	1,529	761	785	104	232	14	539	66	16	121	35	50	69	80	13	4,414

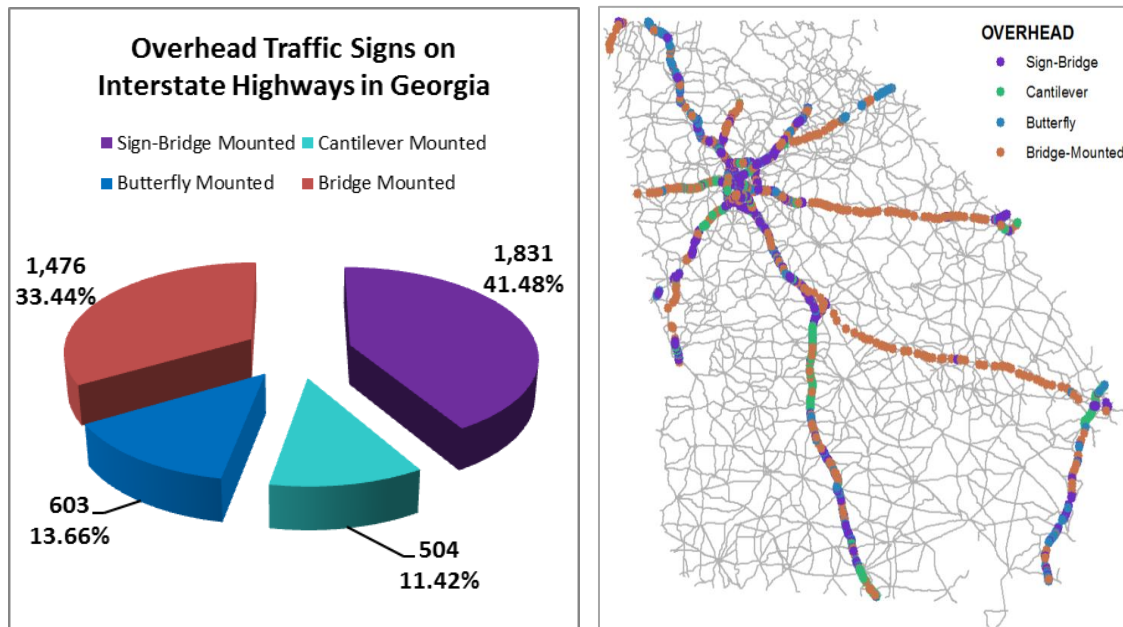


FIGURE 3-7

Traffic signs installed on overhead structure on interstate highways in Georgia

Among all the working districts, District 7 covers the most of the traffic signs, approximately 30% (i.e., 6,683 signs) of the total interstate traffic signs, because of the

district covers the majority of the urban interstate highways also with the highest traffic sign density (i.e., 11.3 signs/mile). District 4 covers the least number of the traffic signs, approximately 8% (i.e., 1,719 signs) of the total interstate traffic signs, because of short mileage the district covers; District 2 has the lowest traffic sign density (i.e., 6.5 signs/mile). FIGURE 3-8 shows the distribution of the interstate miles in the seven districts and the corresponding numbers of traffic signs within each district. TABLE 3-3 shows the detailed numbers and percentage of traffic signs in each working district.

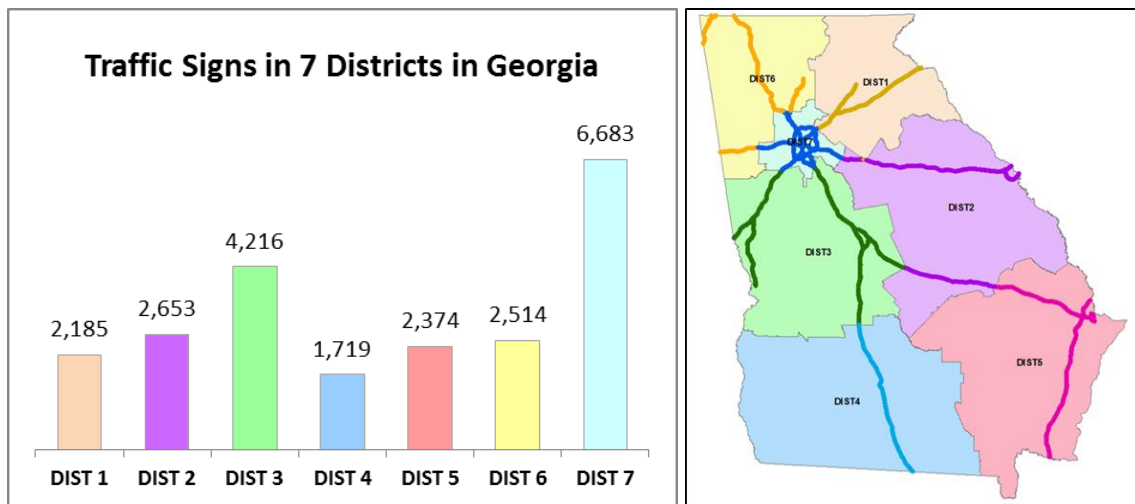


FIGURE 3-8

Distribution of the interstate traffic signs in the 7 working districts

TABLE 3-3

Detailed numbers of traffic signs in each working district

	DIST 1	DIST 2	DIST 3	DIST 4	DIST 5	DIST 6	DIST 7	Total
Number of Signs	2,185	2,653	4,216	1,719	2,374	2,514	6,683	22,344
Percentage	9.8%	11.9%	18.9%	7.7%	10.6%	11.3%	29.9%	100.0%

FIGURE 3-9 shows the distribution of the traffic signs in poor condition in the seven working districts. Similarly, it can be observed that District 7 has more traffic signs in poor conditions (i.e., 335 signs, approximately 5% of the total signs in District 7) than the

ones in other districts. While surface failure is the major reason in all working districts for traffic signs in poor condition, it should be noticed that traffic signs with dirty surfaces occur more frequently in District 6 and obstruction and post failure in District 7. These observations may provide some insight in guiding an improved maintenance effort, such as traffic sign cleaning in District 6 and post repair and vegetation trimming in District 7. TABLE 3-4 shows the detailed statistics.

TABLE 3-4

Detailed statistics of traffic signs in poor conditions in each working district

	DIST 1	DIST 2	DIST 3	DIST 4	DIST 5	DIST 6	DIST 7	Total
Surface Failure	35	38	59	33	38	44	143	390
Post Failure	1	6	14	1	16	26	59	123
Dirty	25	9	31	4	46	81	67	263
Obstructed	3	1	15	4	8	24	66	121
Total	64	54	119	42	108	175	335	897

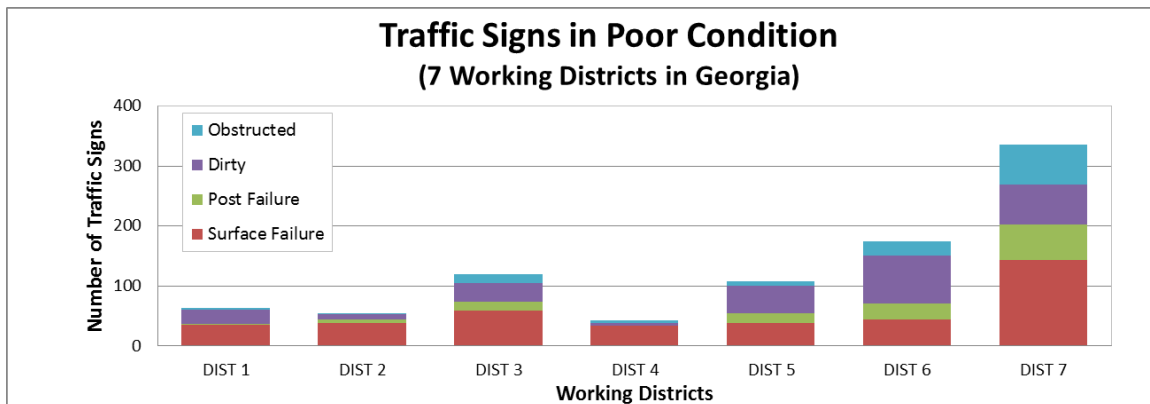


FIGURE 3-9

Distribution of traffic sign in poor condition in the 7 working districts

FIGURE 3-10 shows the distribution of the overhead traffic signs in the 7 working districts. It can be observed that District 7 has a significantly larger number of overhead traffic signs (i.e., 2,022 signs, more than 30% of the total signs in District 7) compared to other districts, because of the frequent overpasses and intersections in the urban region.

The large number and percentage of overhead signs in District 7 may require more maintenance effort and activities compared to other districts. TABLE 3-5 shows the detailed statistics.

TABLE 3-5
Detailed statistics of overhead traffic signs in each working district

	DIST 1	DIST 2	DIST 3	DIST 4	DIST 5	DIST 6	DIST 7	Total
Sign-Bridge Mounted	204	85	201	112	107	132	990	1,831
Cantilever Mounted	21	9	171	44	39	4	216	504
Butterfly Mounted	92	19	103	106	44	88	151	603
Bridge Mounted	65	138	285	104	104	115	665	1,476
Total	382	251	760	366	294	339	2,022	4,414

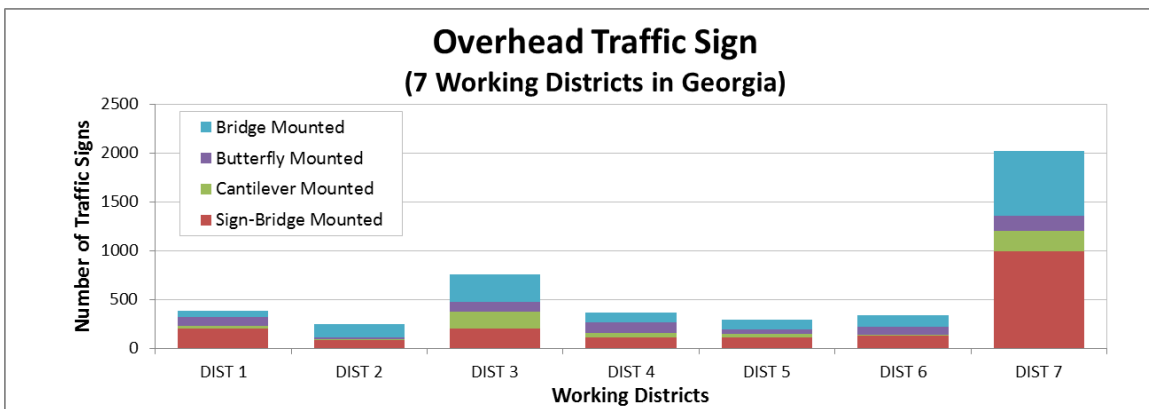


FIGURE 3-10
Distribution of the overhead traffic signs in the 7 working districts

CHAPTER 4. DATA PROCESSING FOR PAVEMENT CONDITION EVALUATION

4.1. Distresses Defined in PACES

GDOT's statewide pavement maintenance budgeting and programming are based on its pavement condition evaluation system, which provides essential data for determining treatment method, estimating cost, and selecting projects. Since 1986, GDOT has conducted annual pavement condition evaluations on its entire 18,000-centerline-miles of state routes based on the PACES survey (GDOT, 2007) (it has been changed to conduct survey biennially since 2015), which was developed by GDOT. PACES was enhanced and upgraded to the COPACES in 1998 (Tsai and Lai, 2002) to a paperless system that enhanced data quality and improved the efficiency of the field data collection system. COPACES surveys are performed by GDOT's engineers during the winter (September to February) without having to employ additional resources. Surveys conducted using COPACES involve recording the severity and extent of various types of pavement surface distresses, including cracking, rutting, raveling, potholes, etc. For cracking, a 100-foot representative section was selected to conduct a detailed walking survey for severity and extent to represent the 1-mile segment (GDOT, 2007). For other distresses, a windshield survey is carried out for the continuous 1-mile segment. The distresses recorded for all the segments (which are typically one-mile long, except for the first and last segment) are then aggregated/averaged to obtain the representative pavement condition for a project (typically several miles long). A COPACES rating (on a scale of 0 to 100 with 100 representing a pavement in excellent condition) is then computed based

on the extent and the severity level of each distress for each segment and project. To enable uniform, impartial data collection and reporting across Georgia, COPACES establishes standardized nomenclature for distresses and defines their respective severity levels and measurement method. There are ten distresses surveyed in COPACES. They are rutting, load cracking, block cracking, reflective cracking, raveling, edge distress, bleeding/flushing, corrugation/pushing, loss of section, and patches/ potholes, as listed in TABLE 4-1. The distress types are categorized and associated with potential causes of the pavement defects, so the data can be used for determining the treatment method. For example, longitudinal cracking and fatigue cracking occurring within the wheel path are considered as load-related cracking (i.e., load cracking), and block cracking is considered as non-load-related cracking due to aging and weathering.

TABLE 4-1
Asphalt pavement distresses defined in COPACES

Distress	Unit	Severity	Survey Length
Load Cracking	%	1, 2, 3, 4	100-foot
Block Cracking	%	1, 2, 3	100-foot
Reflection Cracking	Number, Foot	1, 2, 3	100-foot
Edge Distress	%	1, 2, 3	1-mile
Rutting	1/8 inch	-	100-foot
Patches/Potholes	Number	-	1-mile
Bleeding	%	1, 2, 3	1-mile
Raveling	%	1, 2, 3	1-mile
Corrugation	%	1, 2, 3	1-mile
Loss of Section	%	1, 2, 3	1-mile

4.2. Streamlined Procedure

In this study, a streamlined procedure for pavement condition evaluation following GDOT's COPACES survey method was applied. It aims to improve the productivity and reliability of the data collection practice while keeping field engineers from being exposed to roadway hazards. The procedure utilizes both the available automated methods for pavement distress extraction (including crack, rutting, and raveling) and several customized interactive tools for the extraction of other characteristics. FIGURE 4-1 shows the flowchart of the proposed procedure, which consists of five primary steps. The QA/QC steps are used to guarantee the quality of the extraction results. Since the automatic results are generated covering all the interstate highways with asphalt surface using the interval of a frame in the sensing data collection (i.e., 5 m), the steps of COPACES boundary identification, and COPACES rating generation steps were proposed to summarize the automatic results into COPACES reporting unit, i.e., segments and projects. New reporting segments and projects are generated for the locations without any previous COPACES reporting. In the following sections, the mechanisms for matching existing COPACES reporting segments and projects for generating new COPACES reporting segments and projects are presented.

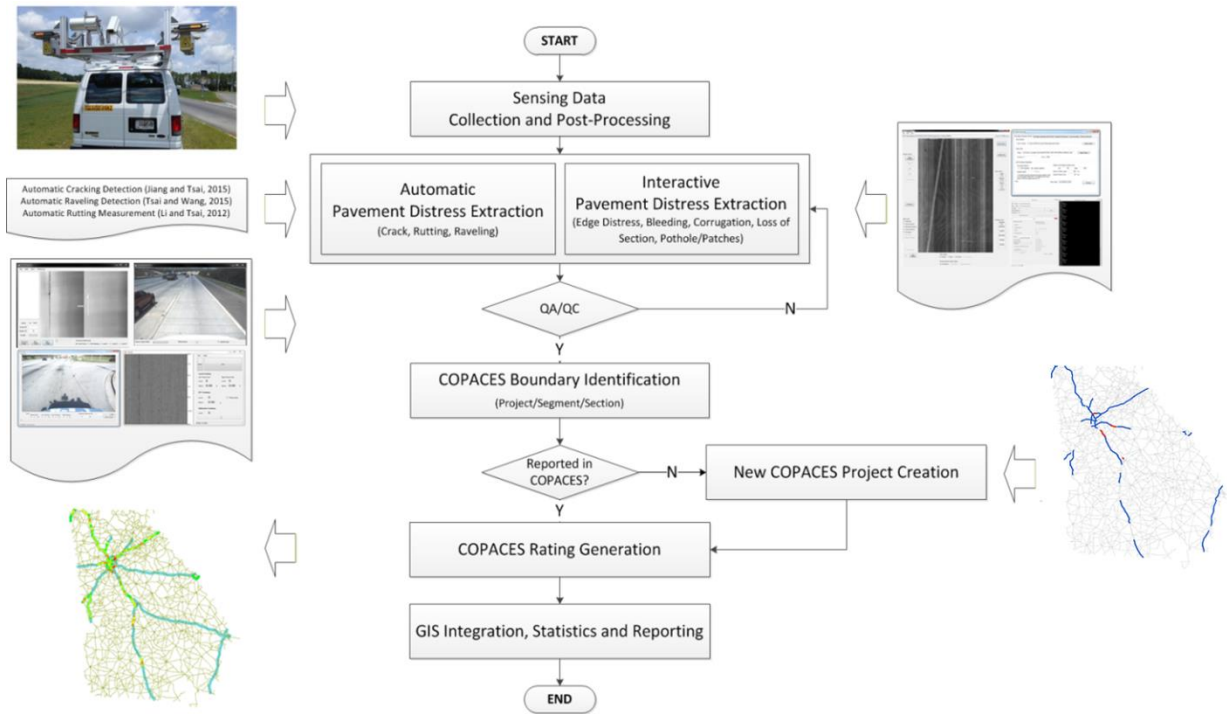


FIGURE 4-1

Flowchart of the proposed streamlined sign data collection procedure (Jiang and Tsai, 2016; Tsai, 2015; Tsai and Wang, 2013; Tsai and Wang, 2014; Tsai and Li, 2012)

4.2.1. COPACES Reporting using Automatic Results

Because the automatic results are reported based on the interval of data frame acquisition, i.e., 5 m interval, the COPACES reporting from the automatic results requires spatial correlation and aggregation. Especially for cracking (including load crack, block crack and reflective crack), the COPACES reporting is generated based on a 100-foot representative section within the survey segment. Therefore, two procedures were proposed for spatially correlating the COPACES survey segments and for aggregation and selection of the representative 100-foot section, respectively.

- Spatial correlation for COPACES survey segments

The collected sensing data are geo-referenced using accurate GPS coordinates so that the results of automatic pavement distress extraction are also geo-referenced with the same GPS coordinates. First, the data frames are spatially joined to the COPACES survey segments using ArcGIS so that each data frame is also a linear referenced system using RCLINK and mile point. Hence, there are approximately 320 data frames linearly referenced within a 1-mile COPACES segment, while each type of pavement distress is individually reported within each data frame.

1,452.5 miles of asphalt-surfaced interstate highway was identified. In order to assess the completeness of the FY2015 COPACES database, Georgia Tech research team made additional effort to identify the pavement types for all the collected data frames covering all the interstate highways in Georgia, including asphalt, concrete, and bridge surfaces. The FY2015 COPACES database reports total 1,384.7 miles of interstate highway and cover 95.3% of the asphalt-surfaced interstate highway in Georgia. 338,284 data frames were spatially correlated with the corresponding interstate segments reported in the FY2015 COPACES database.

- 100-foot representative section aggregation and selection for crack survey

In COPACES, walking survey is conducted for cracking in a 100-foot representative sample section in each 1-mile segment. Using the automatic pavement distress extraction results, the research team reported the detailed difference for each data frame (i.e., 5 m interval). Therefore, for each 1-mile segment, the automatic results can generate fifty-two

100-foot sections, whereas results from six data frames are aggregated for the corresponding 100-foot section. FIGURE 4-2 illustrates the fifty-two 100-foot sections reported within a 1-mile segment. In order to mimic the selection criteria performed by GDOT for a representative section, the deduct value for each individual section is computed, whereas a 60 percentile of the deduct distribution is used for selecting the “representative” section to represent the 1-mile segment. Therefore, the severity level and extent values for the selected “representative” section are used to represent the entire 1-mile segment. The percentile is calibrated by comparing the results from the automatic crack extraction and the results manually reviewed by field engineers from GDOT. It is observed that 60 percentile can best capture the field engineers’ judgment in selecting the “representative” section. It should be noted that although a 60 percentile is used to generate the COPACES ratings in this study, the derived results using the automatic distress extraction have the capability to generate a full-coverage, continuous crack severity level and extent values without the need to aggregate into the “representative” 100-foot section artificially.

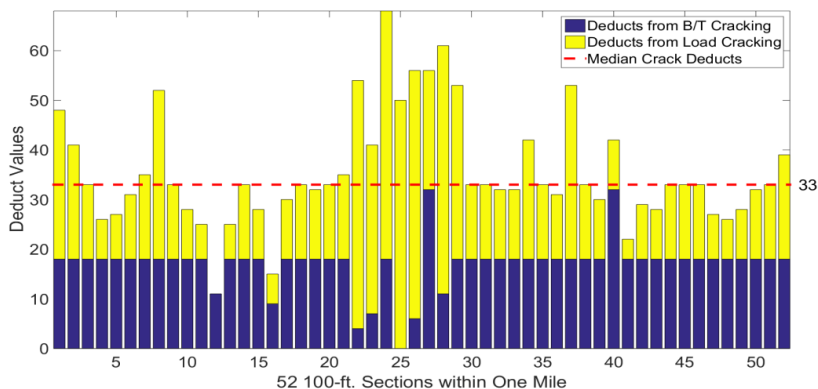


FIGURE 4-2

Illustration of the fifty-two 100-foot sections reported within a 1-mile segment

4.2.2. Generation of New COPACES Segments

As mentioned in the above section, the FY2015 COPACES survey covers 95.3% of the interstate highways with an asphalt surface, which indicates approximately 4.7% of the interstate highways with asphalt surface in Georgia were not reported in the FY2015 COPACES database. It is necessary to append the unreported locations to the full COPACES database. It is necessary to append the unreported locations to the full COPACES survey. FIGURE 4-3 shows the locations of the interstate highways with asphalt surface by a blue line showing the reported locations and a red line showing the unreported locations in the FY2015 COPACES database by GDOT. It is observed that small portions of I-75, I-20, and I-285 were not reported.

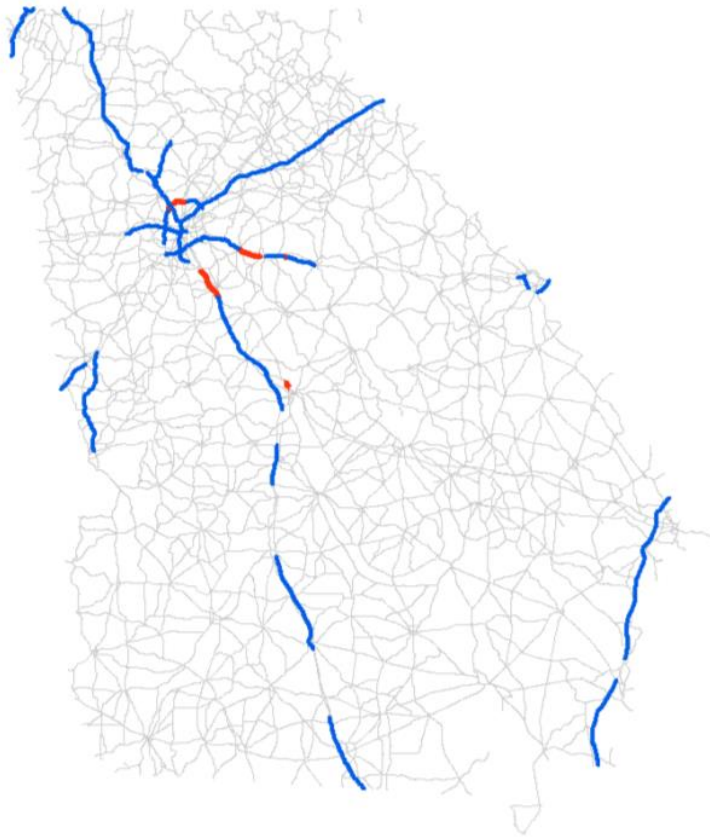


FIGURE 4-3

Locations and extents of the interstate highways with asphalt surface

As recommended by the PACES manual, the following breakpoints are considered to split the unreported locations into new COPACES projects, including interstates, state routes, county lines, and changes in the number of lanes. In addition, all the projects that are greater than 10 miles were double-checked to ensure the pavement conditions and characteristics are homogeneous within the limit. By applying these rules, 14 new projects were generated covering 67.8 miles of interstate highway that had not been previously reported in the FY2015 COPACES database; the corresponding 79 new 1-mile segments were created within the limit of new projects.

4.3. Results

In this study, the COPACES ratings were computed for 1,513 COPACES segments, covering the full length of the interstate highways with an asphalt surface, including 1,434 segments that were defined in the FY2015 COPACES database and 79 new segments. FIGURE 4-4 shows the overview of the derived COPACES ratings. Overall, the pavement condition on interstate highways in Georgia is relatively good, except for a few sections on I-75 close to Tennessee, on I-20, and on I-85 close to Atlanta, etc. These sections contain some extensive distresses due to the age of the pavement and a high volume of truck traffic. It is noted that the average rating derived from the sensing data collected in August 2015 (in FY2016) is 85.6, whereas the average rating of the interstate highway reported in the FY2015 COPACES database is 88.5.

Detailed COPACES deducts in the major distresses, such as load cracking, block cracking, raveling, and rutting, were further studied, as shown in FIGURE 4-5. It can be observed that the overall deduct value related to load cracking, block cracking, and

rutting on interstates is relatively low. Most of the load-cracking-related deduct value is below six points (i.e., less than 10% of load cracking at Severity Level 1); it is below seven points for block cracking (i.e., less than 30% of block cracking at Severity Level 1); and it is below five points for rutting (i.e., less than ¼ inch). However, the majority of the deducts contributed by raveling are above eleven points (i.e., more than 45% of raveling at Severity Level 1, or more than 25% of raveling at Severity Level 2).

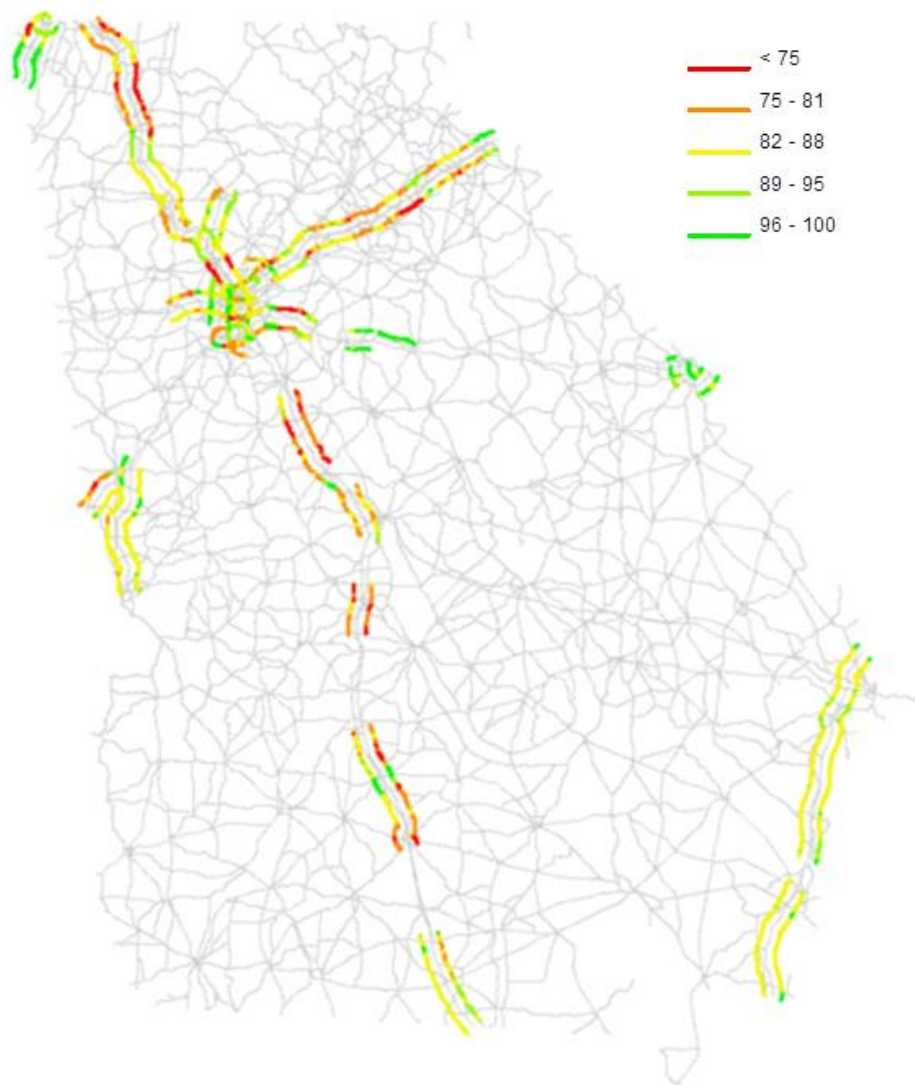
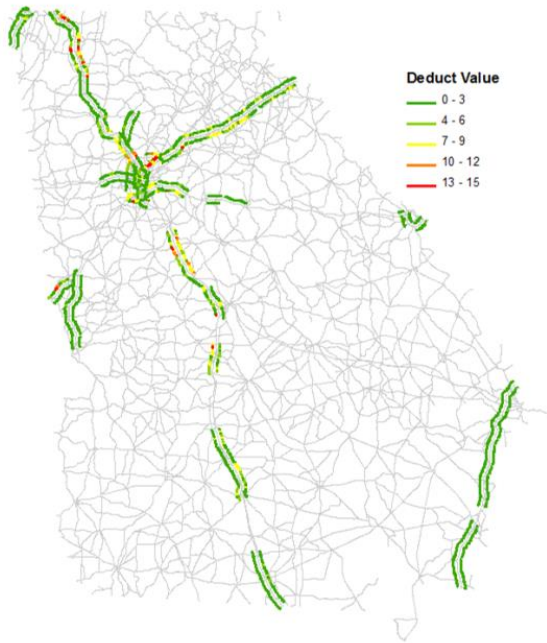
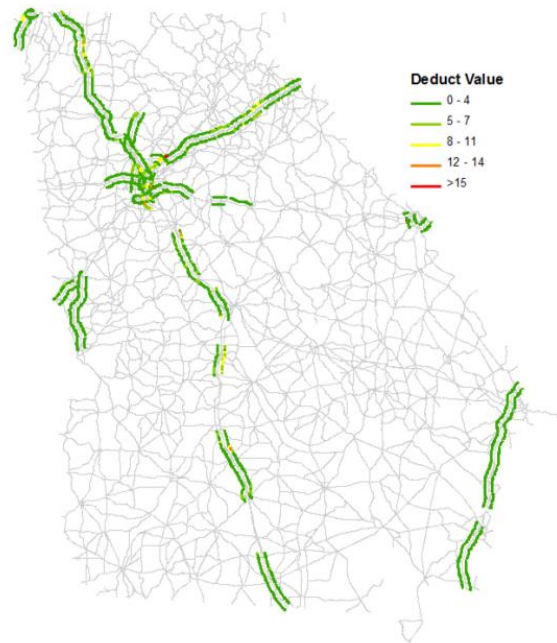


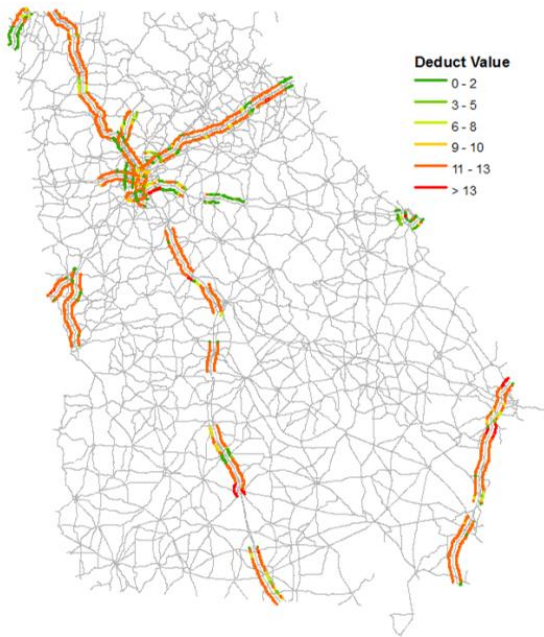
FIGURE 4-4
Derived COPACES ratings using the proposed method



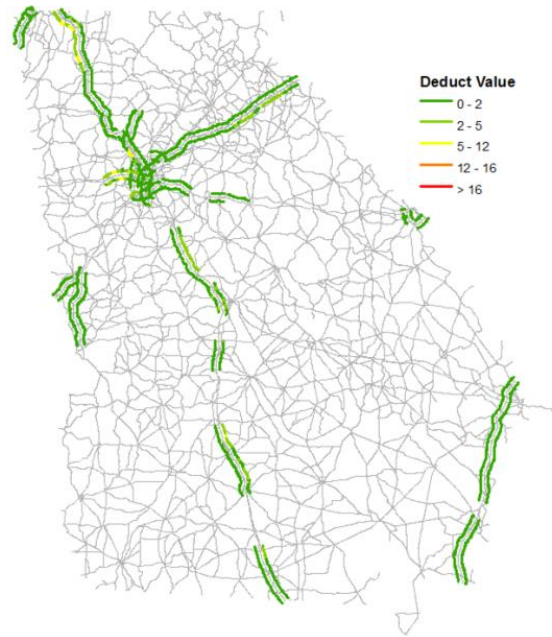
LOAD CRACKING



BLOCK CRACKING



RAVELING



RUTTING

FIGURE 4-5

Distribution of the deducts from the different pavement distresses

CHAPTER 5. BENEFITS OF THE STREAMLINED PROCEDURES

5.1. Benefits of Streamlined Traffic Sign Inventory

Based on a review of sign inventory literature, the current traffic sign inventory method carried out by state DOTs, including GDOT, is primarily a manual process that includes a field engineer's physically collecting a sign's attribute data in the field. For efficiency, personal digital assistants (PDAs), as shown in FIGURE 5-1 (a), barcode scanners, and GPS devices are used in GDOT's inventory. Some state DOTs also use digital cameras (Rasdorf et al., 2009). FIGURE 5-1 (b) shows the process of traffic sign inventory using a PDA. In many transportation agencies' practices, a manual survey using PDAs provides a means for traffic sign inventory, but the process is time-consuming and unsafe due to two major drawbacks: 1) field engineers are required to approach traffic signs to collect the data. Many traffic signs are close to the roadside, in medians, or overhead, etc., which make getting to them very difficult, time-consuming, and, sometimes, dangerous; 2) the distribution of the traffic signs requires extensive amounts of travel time.



FIGURE 5-1
The PDA used in GDOT and field operation in GDOT

On the contrary, the proposed streamlined procedure using sensing data (including video log images, mobile LiDAR, etc.) demonstrates a safer, more reliable, and more cost-effective means for state DOTs. It is estimated the average processing time for each mile of interstate highway is approximately 13 min (approximate 1.5 min/sign). On average, the algorithm used approximately 2 minutes to process each mile of data. An additional 11 min/mile was needed on average including data collection (2 min/mile), interactive review (2 min/mile), MUTCD code input (6 min/mile), and geodatabase integration (1 min/mile). With the help of field engineers from GDOT, it was estimated that the inventory productivity is approximately 98 min/mile (12 min/sign). Research conducted by the Louisiana Department of Transportation and Development (LaDOTD) identified that the average data collection rate is 43 min/sign (Wolshon, 2003). Regardless of the productivity, the manual process becomes increasingly infeasible for interstate data collection because the high-traffic volume, high-traffic speed, large percentage of trucks, and limited space for parking hinders the practicality of the manual process. The proposed streamlined procedure shows significant improvement in productivity in comparison to the current practice.

5.2. Benefits of Streamlined Pavement Condition Evaluation

The COPACES survey procedure has been used by the OM annually (it has been changed to be biennial since 2015) for almost two decades. The outcome of the survey has been consistent and well accepted by field engineers and decision-makers in GDOT. However, due to the nature of a manual survey, the following observations emerged by investigating the COPACES survey results on interstate highways in Georgia, including:

- Some segments of the interstate highways are difficult for conducting manual COPACES survey because of safety concerns caused by limited parking space along high-volume, high-speed corridors. Similarly, the consistency of selecting a “representative” section for cracking survey is difficult to be maintained on interstate highways because of the practical challenge of finding a parking space;
- With the wide use of open graded friction course (OGFC) on interstate highways, raveling has become a primary pavement distress on the interstate highways in Georgia. However, the traditional windshield survey may potentially overlook many of the raveled sections based on surveyor’s visual inspection because of the appearance of raveling, especially the low-level raveling, changes under different lighting conditions and the assessment vehicle’s traveling speed.

Two cases were identified by the research team to compare the results derived from the proposed streamlined procedure to the results from the field survey as reported in the FY2015 COPACES database. The outcomes of these cases clearly demonstrate the potential benefit of the proposed streamlined procedures.

5.2.1. Case 1 - Load/Block Crack Survey Based on “Representative”

Section

“Representative” section was introduced in the PACES manual in order to balance the manual survey effort and the quality of survey results in one mile. However, it becomes more challenging for the field engineers to select “representative” sections on interstate highways than they do on non-interstate highways. In practice, while field engineers make the best effort possible to avoid selecting the best or the worst section as a

representative section in a one-mile segment, a recorded section is typically selected at the location where safe shoulder parking is possible. FIGURE 5-2 shows a sample segment on I-75 northbound near Tennessee (i.e., Segment #248; the color in the figure indicates the level of difference between the derived result using the proposed method and the results reported in the FY2015 COPACES database). The overall rating reported in the FY2015 COPACES database for this segment is 55, while the derived result using the proposed method for this segment is 82. The primary difference in the deduct value is from the load cracking (14 vs. 0) and block cracking (18 vs. 4).

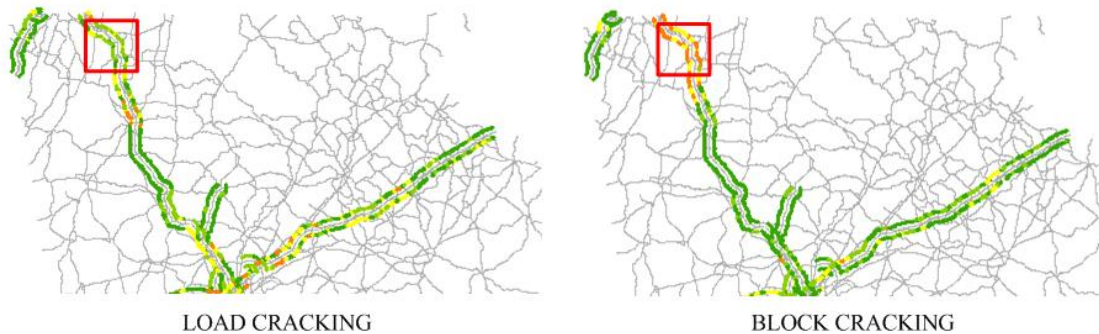


FIGURE 5-2

Sample segment on I-75 NB with different deducts from load cracking and block cracking

The research team looked into the segment in detail to investigate the sources of the deduct difference. The rating reported in the FY2015 COPACES database shows that the field survey was conducted in Sample Location #2 (i.e., MP 11.9 - MP 11.8). As the research team conducted a continuous survey for the full mile and then used 60 percentile of the deducts as the criteria for selecting the “representative” section, the deducts were plotted for all the 100-foot sections within the segment, as shown in FIGURE 5-3. It can be observed that both the load cracking and block cracking were concentrated in the

sections 6-10, while the rest of sections contain fewer load and block cracks.

Coincidentally, sections 6-10 are the same sections for which the field engineers conducted a detailed survey. Hence, the field survey happened to capture the worst sections within the segment instead of the “representative” ones. A further investigation showed that sections 6-10 present a better parking space, while the remainders of the sections present narrower shoulders due to the placement of guardrails and concrete barriers.

It is noted that although the field engineers conducted the field survey based on their best understanding and attempt to select the “representative” section for the detailed crack survey, practical issues, such as the availability of safe parking space, may prevent the engineers from selecting the most “representative” section. Therefore, many of the crack severity levels and extents may not necessarily represent the entire one-mile segment. On the contrary, the sensing-based method proposed by the research team has a full coverage of the segment, so that either a “representative” section could be consistently selected based on the distribution of all the fifty-two sections within the segment or computation could be based on the entire segment instead of a smaller “representative” section.

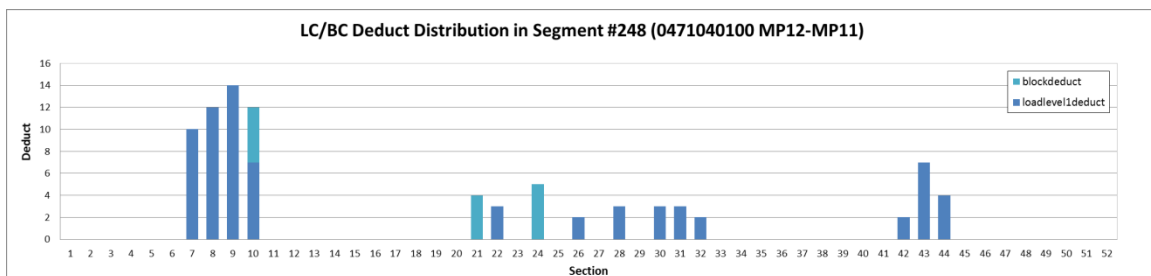


FIGURE 5-3

Distribution of the load cracking and block cracking in Segment #248

5.2.2. Case 2 – Raveling Survey

The results derived from the proposed method show a large extent of raveling on the interstate highways in Georgia and a majority of the raveling is at Severity Level 1, as shown in FIGURE 4-5. FIGURE 5-4 shows the extent difference between the reported and derived raveling extents for all the segments. It can be observed that while the derived results capture more segments containing raveling, the derived results report a higher percentage of raveling (i.e., extent).

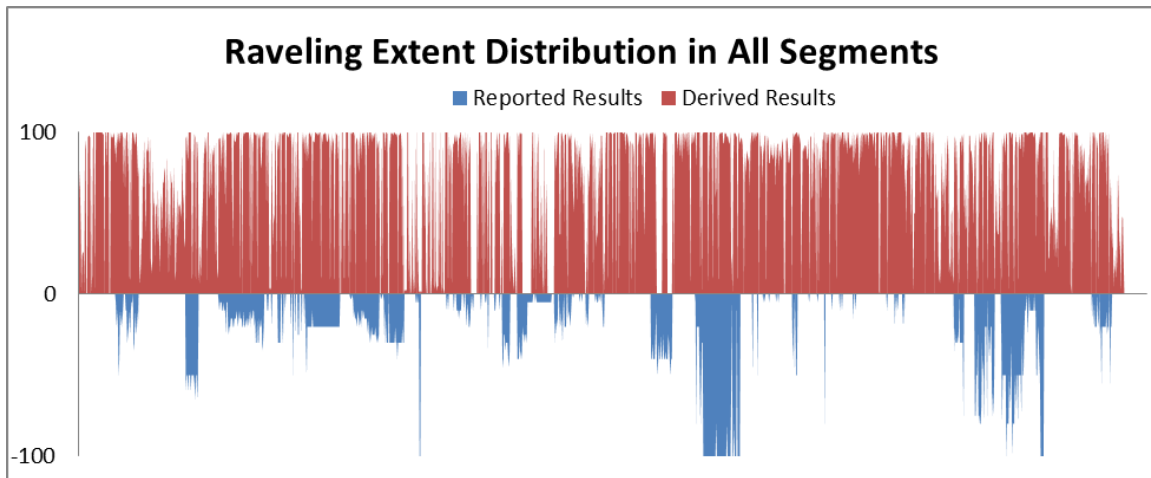


FIGURE 5-4

Raveling extent difference in all of the 1-mile segments covering interstate highways in Georgia

To further investigate whether the derived method over-estimates raveled area or the field survey tends to overlook many of the raveled areas, the research team compared different data sources of the pavement. FIGURE 5-5 shows a sample section collected in Segment #811 on I-75 Southbound. In the results reported in the FY2015 COPACES database, the deduct value for raveling is zero (i.e., no raveling), whereas a deduct value of 13 for raveling was derived using the proposed method (i.e., Severity Level 1 raveling >45%).

FIGURE 5-5(a) shows the front view video log image that is similar to the field engineer's view during the windshield survey; FIGURE 5-5(b) shows the 3D pavement-scanning image; FIGURE 5-5(c) shows the side-view image captured on the shoulder; FIGURE 5-5(d) shows the lost aggregates accumulated in the rumble strip on the shoulder. It can be observed that it is challenging to observe raveling using only the front-view video log image, especially when the raveling is still at the early stage, as shown in this case. However, based on the side-view and the slight aggregate accumulation in the rumble strip, the raveling could be confirmed. Using the developed automated raveling extraction algorithm and the 3D pavement data, the streamlined procedure can capture and reveal the raveling at the early state when only a few aggregates were lost.

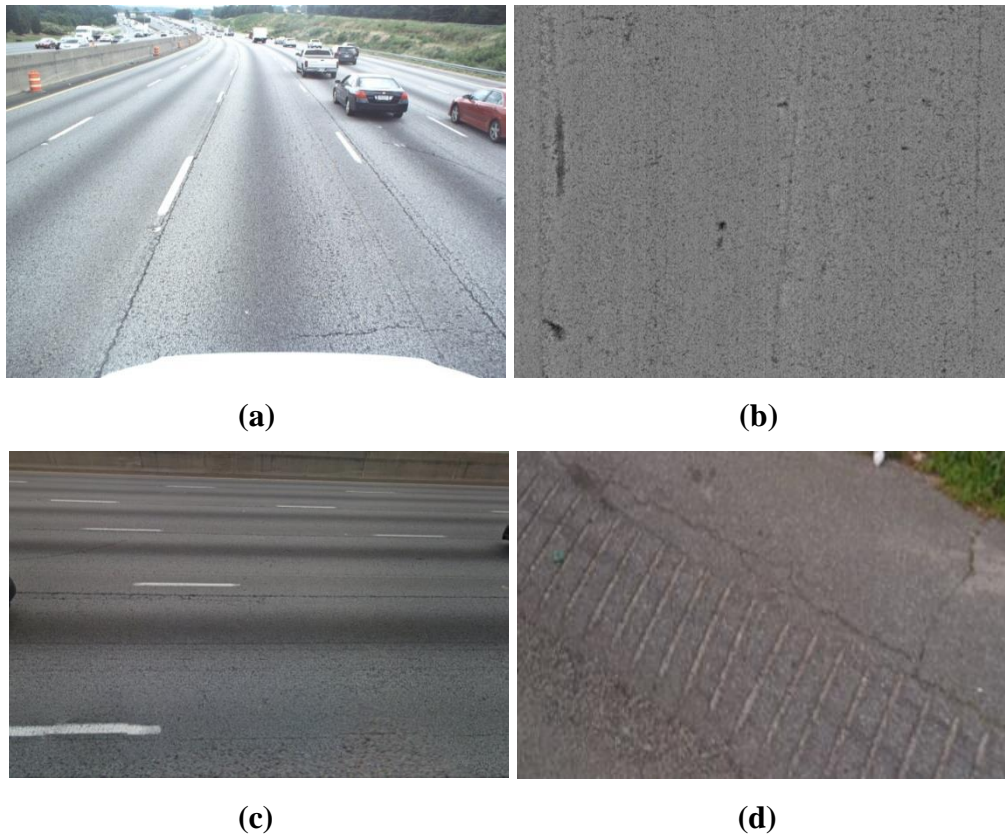


FIGURE 5-5
Sample images for Segment #811 on I-75 SB

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Traffic signs are important for roadway safety and provide critical guidance to road users with traffic regulation, road hazard warnings, destination information, and other geographic information. However, most of the inspection programs carried out by transportation agencies, like GDOT, are manual methods, which require field engineers to physically inspect and record the information of each individual traffic sign, which takes excessive time, consumes great amounts of labor, and sometimes exposes field engineers to roadway hazards. Although GDOT has a handheld-based data collection method for traffic sign inventory and condition evaluation, the process requires significant amounts of labor, equipment, and time, and it is hazardous to the field engineers when data collection is conducted near high-speed, high-volume traffic. GDOT currently does not have a complete sign inventory on its interstate highway system. Therefore, GDOT needs a safer and more cost-effective means to collect traffic sign data, especially on high-speed, high-volume interstate highways.

Pavements are one of the most critical infrastructures for providing safe, uninterrupted, and comfortable trips for drivers to reach their destinations. As one of the most invested infrastructures in many public transportation agencies, GDOT critically needs pavement surface distress data to monitor its statewide pavement conditions, identify maintenance activities, and optimally allocate pavement funds. The OM collects the statewide pavement condition data annually based on the distress protocol defined in GDOT's PACES (it has been changed to biennial data collection since 2015). The current manual

method works well on state-maintained, non-interstate roadways, but it is difficult and, sometimes, prohibitive for surveying interstate highways due to the safety concerns caused by limited parking space for field engineers and high-speed, high-volume traffic. Therefore, GDOT needs a safer and more cost-effective method to complement its manual method of data collection on interstate highways.

In the national demonstration project performed by Georgia Tech research team, streamlined traffic sign inventory and pavement condition evaluation procedures have been developed. In these streamlined procedures, automatic traffic sign detection (using mobile LiDAR and video log image data) and an automatic pavement distress detection and classification method (including cracking, rutting, raveling, etc.) that uses emerging 3D line laser imaging technology have been incorporated to enhance inventory data quality and productivity. Based on the discussions with the OM and the OR, all interstate highways in Georgia are selected for this case study because these interstate highways are the major capital investments for GDOT. The collected traffic sign data can be input into GDOT's current asset management system, while the pavement condition data will be stored in GDOT's COPACES database and can be further consumed and/or integrated into the GAMS.

In this research project, a complete and comprehensive traffic sign inventory for interstate highways and a complete and comprehensive pavement condition evaluation for all asphalt-surfaced interstate highways in Georgia were established using the streamlined traffic sign inventory and pavement condition evaluation procedures. The following summarize the outcomes of this implementation projects:

1. **22,344** traffic signs were inventoried along all the interstate highways in Georgia.

Among all the identified signs, the majority of the signs are guide signs that make up 62.0% (13,857 signs) of the total population. The rest of the population consists of 3,692 regulatory signs, 3,209 warning signs, 1,490 other signs (customized signs in Georgia), and 96 temporary signs.

- There are **897** signs (4.0% of the overall traffic sign population) in poor condition requiring sign maintenance actions, including:

- 1) Surface failure (390 signs, 43.5%)
- 2) Dirty (263 signs, 29.3%)
- 3) Post failure (123 signs, 13.7%)
- 4) Obstructed (121 signs, 13.5%)

- There are **4,414** overhead signs (19.8% of the overall traffic sign population). They have a high potential risk and require frequent monitoring and condition assessment. They are divided into four categories and inventoried by location (i.e., latitude and longitude coordinates):

- 1) Sign-Bridge (1,831 signs, 41.5%)
- 2) Bridge-Mounted (1,476 signs, 33.4%)
- 3) Cantilever (504 signs 11.4%)
- 4) Butterfly (603 signs, 13.7%)

- Through processing the large-scale dataset collected on the interstate highways in Georgia, the productivity of sign inventory has been significantly improved by employing the streamlined traffic sign inventory procedure, which uses sensing data. It is estimated that an average of 13 min/mile (1.5 min/sign, on average 8

signs/mile on interstate highways in Georgia) might be achieved for traffic sign inventory using the proposed procedures, which is 1~1.5 times faster than the average 25~30 min/mile (3~4 min/sign) using manual method. In addition, the safety improvement and the reduction of survey vehicles' stop-and-go fuel consumption are also potentially significant, especially on interstate highways.

2. **1,513** miles of COPACES segments were rated using the streamlined pavement condition evaluation procedure and the sensing data. The results cover the full length of the interstate highways with an asphalt surface, including 1,434 segments surveyed in the FY2015 COPACES database and 79 new segments. The segment results were further aggregated into 316 COPACES projects, including 302 projects from the FY2015 COPACES database and 14 new projects. The COPACES ratings derived from the streamlined pavement condition evaluation procedure and the COPACES ratings surveyed by field engineers in GDOT show very similar trends. The following observations are made by comparing two selected projects that were surveyed by GDOT using the conventional method:

- It is identified that some of the selected “representative” sections may be biased due to the practical challenges encountered by field engineers during interstate data collection, e.g., the availability of shoulder parking spaces. On the contrary, since the streamlined procedure continuously extracts cracks for the full coverage of the roadway and then selects the section based on a consistent 60 percentile deduct for each 1-mile segment, the results can well capture the “representativeness” of the section for the corresponding 1-mile segment.

- It is identified that the manual survey conducted by field engineers may overlook or underestimate the severity and extent of raveling due to the nature of a windshield survey, especially when the road is not continuously raveled. On the contrary, since the streamlined procedure continuously identifies and classifies raveling for the full coverage of the roadway, the results can well capture the overall raveling condition without overlooking the isolated raveled segments.

This study has demonstrated that the proposed streamlined procedures provide a consistent, reliable, and cost-effective means for traffic sign inventory and pavement condition evaluation, especially on interstate highways. Through processing the large-scale dataset collected on the interstate highways in Georgia, the research team observed significant productivity benefits by employing the streamlined procedures for traffic sign inventory and pavement condition evaluation using sensing data. The research team recommends the streamlined procedures be employed to sustain and improve GDOT's long-term interstate highway inventory, condition evaluation, and maintenance program. In addition, the developed procedures will enable GDOT to cost-effectively extract COPACES data, using the 3D data to be collected in the future by vendors with a proper data collection specification. In addition, to leverage the collected mobile LiDAR data, it is recommended to evaluate the feasibility of using mobile LiDAR for a large-scale, automatic traffic sign retroreflectivity condition assessment.

REFERENCES

- Ai, C., and Tsai, Y.-C. J. (2015). "Critical Assessment of an Enhanced Traffic Sign Detection Method Using Mobile LiDAR and INS Technologies." *Journal of Transportation Engineering*, 141(5), 04014096.
- FHWA (2013). "Guidelines for the Installation, Inspection, Maintenance and Repair of Structural Supports for Highway Signs, Luminaries, and Traffic Signals." Federal Highway Association. Accessed online on Feb. 1, 2016, at <https://www.fhwa.dot.gov/bridge/signinspection.cfm>
- GDOT (2007). "Pavement Condition Evaluation System." Office of Maintenance.
- GDOT (2008). "Foreman's Academy – Traffic Sign Training in Georgia Department of Transportation."
- Hensing, D. J., and Rowshan, S. (2005). "Roadway Safety Hardware Asset Management Systems Case Studies." Technical Report FHWA-HRT-05-073, Washington DC.
- Jiang, C., and Tsai, Y. J. (2016). "Enhanced Crack Segmentation Algorithm Using 3D Pavement Data." *Journal of Computing in Civil Engineering*, 30(3), 04015050.
- Luh, D., and Tsai, J. (2012). "Interactive Traffic Sign Inventory Tool." Internal Software, Georgia Institute of Technology.
- Rasdorf, W., Hummer, J. E., Harris, E. A., and Sitzabee, W. E. (2009). "IT Issues for the Management of High-Quantity, Low-Cost Assets." *Journal of Computing in Civil Engineering*, 23(2), 91-99.
- Tsai, J. (2009). "Using Image Pattern Recognition Algorithms for Processing Video Log Images to Enhance Roadway Infrastructure Data Collection." National Academy of Science NCHRP IDEA-121.

- Tsai, J. (2015). "Development of an Asphalt Raveling Detection Algorithm Using Emerging 3D Laser Technology and Macrotexture Analysis." National Academy of Science NCHRP IDEA-163.
- Tsai, J., and Wang, Z. (2013). "Remote Sensing and GIS-enabled Asset Management System (RS-GAMS): Phase 1." USDOT RITA National Consortia on Remote Sensing in Transportation, DTOS59-10-H-0003.
- Tsai, J., and Wang, Z. (2014). "Remote Sensing and GIS-enabled Asset Management System (RS-GAMS): Phase 2." USDOT RITA National Consortia on Remote Sensing in Transportation RITARS-11-H-GAT.
- Tsai, Y.-C. J., and Li, F. (2012). "Critical Assessment of Detecting Asphalt Pavement Cracks under Different Lighting and Low-Intensity Contrast Conditions Using Emerging 3D Laser Technology." *Journal of Transportation Engineering*, 138(5), 649-656.
- Tsai, Y., and Lai, J. S. " A Framework and Strategy for Implementing An IT-Based Pavement Management System." *Proc., 81st Transportation Research Board*.
- Wolshon, B. (2003). "Louisiana Traffic Sign Inventory and Management System Report-381." Louisiana Transportation Research Center, Baton Rouge.