GEORGIA DEPARTMENT OF TRANSPORTATION

Final Report

Optimization of Safety on Pavement Preservation Projects

Prepared for:

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III. Executive Summary

To achieve a goal of reducing highway crash fatalities by 4% each year to improve roadway safety, the Georgia Department of Transportation (GDOT) is actively seeking opportunities to incorporate safety improvements into its current pavement preservation program. The pavement preservation program, especially resurfacing activities, can effectively address safety concerns, such as hydroplaning and skidding, caused by pavement deficiencies, such as deep rutting, low skid resistance surface, inadequate superelevation, etc. With severe funding shortages in recent years, GDOT has experienced an increasing number of deferred resurfacing projects, which exacerbates pavement deficiencies, raises safety concerns, and, consequently puts the general public and GDOT at risk. Integrating safety improvements into the existing resurfacing program provides GDOT an opportunity to not only address the aforementioned issues, but also optimize limited resources and minimize traffic interruptions to the general public. Therefore, a means for incorporating safety improvements into GDOT's existing resurfacing program is much needed and has been studied in this research.

Although many state transportation agencies incorporate safety improvements into pavement resurfacing, rehabilitation, and reconstruction (3R) projects by implementing the design guidelines and/or road safety audit programs, limited safety improvements can be incorporated into the fast-paced resurfacing program. In fact, resurfacing projects are often prioritized based on pavement conditions but do not consider safety concerns. To the best of the authors' knowledge, no methodologies have been published that address the integration of safety improvements and resurfacing projects at various levels (e.g., training, data integration, prioritization, programming, etc.). Therefore, the objective of this project (Phase 1) is to propose a safety-incorporated resurfacing program that will enable GDOT to effectively and systematically incorporate safety improvements into its existing fast-paced resurfacing program, which is one of the most common pavement preservation methods. The implementation of the proposed program will be completed in Phase 2. Several tasks were undertaken to accomplish the objective, including the following:

- Review state practices for incorporating safety improvements into 3R activities;

- Review GDOT's existing pavement resurfacing program and safety improvement program;
- Propose a safety-incorporated resurfacing program that effectively incorporates safety improvements into GDOT's existing fast-paced pavement resurfacing program; and
- Design the functions, database, and refined process to support the implementation of the proposed program.

An enhanced, safety-incorporated program consisting of the following three components is proposed for GDOT to seamlessly integrate safety improvements into its existing fast-paced resurfacing program:

1) First, a safety improvement categorization is proposed to make the integration of safety improvements into the resurfacing program practically feasible by dividing safety improvements into three categories in terms of duration, funding, and office coordination. The three categories are: 1) resurfacing; 2) safety improvements that require no environmental studies; and 3) safety improvements that require environmental studies.
2) Second, a two-stage approach to identify the projects with potential pavement-deficiency-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 is also proposed to quantify the safety concerns/risks identified through the two-stage approach.
3) Third, a project reprioritization method that takes pavement conditions and safety concerns into account is proposed to minimize potential safety risks. To align the reprioritization method with GDOT's current resurfacing prioritization, the safety index is incorporated into the Pavement Condition Evaluation System (PACES) rating computation.

To demonstrate the feasibility of the proposed program, a case study using the actual data of a deferred resurfacing project in Cherokee County, Georgia was conducted. Preliminary results show that project with safety concerns can be identified and moved to a higher priority, and the project may, as a result, be resurfaced earlier.

The proposed safety-incorporated resurfacing program will enable GDOT to 1) identify and reprioritize deferred resurfacing projects with safety concerns to minimize potential risks, 2) take advantage of the existing fast-paced resurfacing program for upgrading Georgia's roadway system to meet enhanced safety standards, and 3) systematically integrate safety improvements into its existing resurfacing program to optimize resources and minimize traffic interruptions to the general public.

1 Introduction

1.1 Background

The Georgia Department of Transportation (GDOT) has had an effective pavement preservation program since the 1980's to cost-effectively extend pavement life in Georgia. With a goal of reducing highway crash fatalities by 4% each year to improve highway safety (GOHS, 2010), GDOT is actively seeking opportunities to incorporate safety improvements into its current pavement preservation program. This project focuses on GDOT's resurfacing program, one of the most common pavement preservation methods. Pavement resurfacing, including replacement of the surface lift of dense-grade asphalt or an open-graded friction course (if present) not to exceed three inches (GDOT, 2011), can redress pavement deficiencies (e.g., deep rutting and low skid resistance) that contribute to crashes associated with pavement surface issues, such as hydroplaning (Zimmerman and Larson, 2005).

Currently, GDOT's pavement resurfacing projects and safety improvement projects are identified, selected, prioritized, and programmed separately by the Office of Maintenance and the Office of Traffic Operations. The resurfacing program, including pavement condition evaluation, project selection and prioritization, budget allocation, and let package preparation, is operated at a fast pace (e.g., within a few months) in order to preserve pavement in a timely manner. The decisions on pavement treatment methods and project prioritization are made primarily based on pavement conditions; however, on a project-by-project basis, safety considerations, such as adding rumble strips or changing project priority for safety concerns, can also be included based on engineers' judgments. There is a need for a systematic decision-making process for incorporating safety into resurfacing projects.

This research to incorporate safety into GDOT's current resurfacing program is motivated by the two forces: 1) to address pavement-induced-deficiency safety concerns and 2) to enable a system-wide roadway upgrade to meet the new safety standards. First, the projects with pavement-deficiency-induced safety concerns can be identified using pavement conditions and crash data and moved to a higher priority. This is especially important to GDOT now because there are more deferred resurfacing projects due to funding shortages (Wang et al., 2009; Wang et al., 2011). Second, proper safety improvements can be integrated into resurfacing projects to cost-effectively upgrade roadways for meeting enhanced safety standards.

Therefore, in this study, we propose a safety-incorporated resurfacing program to integrate safety improvements into the existing resurfacing program at various levels, including training, tools, and data integration, to assist engineers in making informed decisions to improve roadway safety.

1.2 Significance of Research

It is anticipated that the proposed program can systematically incorporate safety into GDOT's current resurfacing program and will enable GDOT to

1) minimize potential pavement-deficiency-induced safety risks due to deferred resurfacing projects;
2) take advantage of the fast-paced resurfacing program to cost-effectively and systematically upgrade existing roadways for enhanced safety standards; and
3) optimize limited resources and reduce traffic interruptions to the general public.

1.3 Research Objectives and Scope

The objective of this project is to propose a safety-incorporated resurfacing program that systematically incorporates safety into GDOT's existing fast-paced resurfacing program. The following are three work tasks undertaken in Phase 1 of this research project to accomplish the objective:

1) **Work Task 1: Literature review of optimizing safety in pavement preservation projects or other operation projects.**

   This work task is to review 1) state practices on integrating safety and pavement resurfacing, restoration, and rehabilitation (3R) projects, 2) GDOT's resurfacing program operated by the Office of Maintenance, and 3) GDOT's safety improvement program operated by the Office of Traffic Operations.

2) **Work Task 2: Design refined processes, database, and functions.**

   This work task is to propose a safety-incorporated resurfacing for GDOT. Georgia Tech research team has worked closely with the Office of Maintenance and the Office of Traffic Operations to develop an enhanced, safety-incorporated resurfacing program that incorporates safety at various levels, including refined resurfacing programming process, tools (e.g., functions), and data integration, to support the proposed program.

3) **Work Task 3: Develop a spatial and temporal search algorithm and prioritization model.**

   This work task is to identify 1) current and upcoming pavement deficiencies that can cause safety risks, and 2) the needs for roadway upgrades to comply with enhanced safety standards. Georgia Tech research team has worked with the Office of Maintenance and the Office of Traffic Operations to develop preliminary criteria for the computerized search and a method for resurfacing reprioritization.

1.4 Organization of This Report

This report is organized into eight chapters, including the following:

1) Chapter 1 introduces the background, significance, objective, and work tasks of this project.
2) Chapter 2 reviews the practices adopted by other state Departments of Transportation (DOTs) for incorporating safety into 3R projects.
3) Chapter 3 reviews GDOT's resurfacing program operated by the Office of Maintenance with a focus on the steps involved in programming a resurfacing project, including pavement condition evaluation, project selection and prioritization, budget allocation, and let package preparation.
4) Chapter 4 reviews GDOT's safety improvement program operated by the Office of Traffic Operations.
5) Chapter 5 presents the proposed program to systematically incorporate safety into GDOT's existing resurfacing program.
6) Chapter 6 presents a case study using actual data to demonstrate the feasibility of the proposed program to identify and reprioritize resurfacing projects with safety concerns.

7) Chapter 7 presents the functions and databases designed to support the proposed safety-incorporated pavement resurfacing program.
8) Chapter 8 summarizes the findings of this project and makes recommendations for future research.

2 Review of State DOTs’ Practices for Incorporating Safety Improvements into 3R Projects

This chapter presents a review of state DOTs’ practices for incorporating safety improvements into 3R projects. First, state DOTs’ practices, including the type of safety improvements to be incorporated, the funding sources, and the selection criteria for safety improvements are presented. Next, the benefits and costs considered for safety improvements selection and prioritization are discussed. Finally, good practices and challenges identified in the literature are summarized.

2.1 State Practices

Recognizing the benefits of integrating safety improvements with 3R projects, many state DOTs have developed their own practices to consider safety in 3R projects and provide assistance to their local agencies for incorporating safety improvements into their 3R projects (Mahoney et al., 2006). In 2006, the Federal Highway Administration (FHWA) conducted a scan tour of several states to document and disseminate information on good practices by state DOTs and local agencies to integrate safety improvements into 3R projects (Mahoney et al., 2006).

Severn state DOTs, including states reviewed by the scan tour and other states with published design guideline or manual on incorporating safety into 3R projects, are reviewed in this section. The practices for incorporating safety into 3R projects with a focus on the types of safety improvements to incorporate, the funding sources, and the safety improvement selection criteria are discussed below.

2.1.1 Colorado

The Colorado Department of Transportation (CDOT) addresses safety requirements for 3R projects in the design bulletin entitled “Procedures for Addressing Safety Requirements on

Resurfacing, Restoration, Rehabilitation (3R) Projects" (CDOT, 2006). According to the design bulletin, a safety evaluation procedure is required for all 3R projects during the project design stage. The safety evaluation is conducted by the Headquarter (HQ) Safety and Traffic Engineering Branch and the regional design team. A Traffic Operational Analysis (TOA), which is an accident history report with a brief recommendation section, or a Safety Assessment Report (SAR), which is a comprehensive analysis of the accident history that includes specific recommendations, can be given to a 3R project during the evaluation process (CDOT, 2006).

Only a few safety improvements, e.g., signing, striping, delineation, shoulder-up work, guardrail adjustments, etc., are allowed to be funded by the Surface Treatment Program funds, other safety improvements are funded by the Safety Enhancements Pool funds in CDOT. Approximately 11 percent of the Surface Treatment Program funds are expended on these safety items (Mahoney et al., 2006).

2.1.2 Iowa

The Iowa Department of Transportation (IADOT) employs the road safety audit (RSA) program strictly during the 3R projects design process. An independent RSA team consists of personnel from IADOT's Office of Traffic and Safety, the FHWA Division Office, the Iowa State University Center of Transportation Research and Education, and other experts who will complete a field review, thoroughly assess the crash records of the highway, and provide feedback on the safety-related features of the proposed design (FHWA, 2006). Safety improvements considered in 3R projects include, but are not limited to the following (Mahoney et al., 2006):

- Improve superelevation;
- Extend small culverts;
- Upgrade guardrail;
- Add 2 to 6 ft. paved shoulders and shoulder rumble strips;
- Add offset turn lanes;
- Flatten transverse driveway entrance slopes;
- Construct safety dikes at T-intersections;

- Remove fixed objects within the clear zone;
- Place chevrons on horizontal curves; and
- Replace warning signs with florescent-yellow signs.

For national highway system (NHS) routes, some additional improvements are also considered (Mahoney et al., 2006):

- Widen travel lanes;
- Upgrade granular shoulders with surface treatments; and
- Convert existing four-lane undivided urban streets to three-lane facilities.

2.1.3 New York

The New York State Department of Transportation (NYSDOT) adopts the Safety Appurtenance Program (SAFETAP), a modified road safety audits (RSA) program, to incorporate safety improvement into 3R project (NYSDOT, 2010). The SAFETAP is required for all 3R projects in the New York State (FHWA, 2006). Typically, an independent Safety Assessment Team consists of licensed professional experts from traffic, design, maintenance, and other areas of expertise is formed at the initial stage of the project scoping. This team will assess 3R projects using the Resurfacing Safety Assessment Form (Appendix I) and make recommendations on which safety improvements should be incorporated (NYSDOT, 2010).

NYSDOT divides safety improvements into pavement and non-pavement works. While only pavement safety improvement works can be performed in resurfacing projects, non-pavement safety improvement works can be employed in other 3R projects. The pavement safety improvement works are listed as the following (NYSDOT, 2010):

- Signing
- Pavement markings
- Delineation
- Sight distance
- Fixed objects
- Guide rail

- Bridge rail transitions
- Railroad crossing
- Rumble strips
- Shoulder resurfacing
- Edge drop-offs
- Superelevation

The non-pavement safety improvement works include the following:

- Speed change lanes
- Clear zone(s)
- Traffic signals
- Shoulder widening
- Lane widening
- Turn lanes
- Curbing
- Drainage
- Others

2.1.4 North Carolina

The North Carolina Department of Transportation (NCDOT) determines that the implementation of safety improvements should be considered in the initial scope of 3R projects (NCDOT, 2004). According to the Guide for Resurfacing, Restoration, and Rehabilitation (R-R-R) of Highways and Streets (NCDOT, 2004), the following improvements are considered at the initial stage of every 3R project:

- Skid resistance: Only the surface course mixes containing aggregates approved by the Material and Test Unit of NCDOT shall be utilized in 3R projects.
- Improvements based on crash data analysis: The Traffic Engineering Branch will analyze crash data and provide safety improvement recommendations. The safety measures range from correction of hazardous alignment to the placement of warning signs and markers.

- Roadside safety: Roadside safety measures include obstructions removal and shielding. Barriers or attenuators are considered in accordance with the Roadside Design Guide published by AASHTO and the standard of NCDOT's Roadway Design Unit.

2.1.5 Oregon

In the Oregon Department of Transportation (ODOT), safety projects are evaluated by the Statewide Transportation Improvement Program – Safety Investment Program (STIP-SIP) (Monsere et al., 2009) and the Traffic-Roadway Section (TRS) of ODOT is in charge of the safety projects' management and selection. The SIP is part of the design process of 3R projects, and safety improvements selection is primarily based on the benefit-cost ratio (ODOT, 2003).

Safety improvements can be funded by the Pavement Preservation funds in ODOT (no more than 6%) for projects with low accident histories. However, for projects with a fatal or serious crash history, safety improvements are typically funded by the Highway Safety Program. In addition, the Highway Safety Program funds are typically used for stand-alone safety improvement projects, yet they may be used in conjunction with other funds (e.g., Pavement Preservation funds) to address safety problems in other projects (e.g., 3R projects) (ODOT, 2010). To be more specific, the use of Highway Safety Program funds on 3R projects is limited to the following guidance (ODOT, 2010):

- For pavement preservation projects on segments with a low crash history, the Highway Safety Program funds should not be expended.
- For pavement preservation projects with a history of fatal or serious crashes, effectiveness of proposed safety improvements shall be examined using benefit-cost analysis. A cost-effective or high potential payback project should be considered to be funded by the Highway Safety Program funds.
- The replacement of existing features on STIP projects (e.g., striping, guardrail, signing, rumble strips) shall not be funded by the Highway Safety Program funds. These features should be funded out of the project's program limitation (e.g., modernization, preservation, bridge, etc.).

2.1.6 Pennsylvania

The Pennsylvania Department of Transportation (PennDOT) provides a comprehensive guideline, such as the safety improvement selection criteria, for incorporating safety into 3R projects in the District Highway Safety Guidance Manual (PennDOT, 2008). The safety improvement selection criteria, including roadway characteristics, crash categories, and number of crashes in a 5-year period, are listed and summarized in Appendix II. Projects involving geometric improvements typically require an environmental study and generally take up to 2 years to implement if no additional right-of-way is required (Mahoney et al., 2006). Safety works without geometric alternations, on the other hand, can be implemented within a shorter period of time.

2.1.7 Washington

The Washington State Department of Transportation (WSDOT) considers safety in resurfacing projects by identifying safety improvements that can be programmed with resurfacing projects in its Design Manual (WSDOT, 2010). These safety improvements are indicated as “Basic Safety” items as follows:

- Install and replace delineation;
- Install and replace rumble strips;
- Adjust existing features affected by resurfacing;
- Adjust guardrail height;
- Replace signing;
- Relocate, protect, or provide breakaway features for sign supports, luminaries, electrical service poles, and other intelligent transportation systems (ITS) equipment inside the Design Clear Zone;
- Restore sight distance (removal or relocation of signs and other obstructions or cutting of vegetative matter);
- Upgrade bridge rail;
- Upgrade barrier terminals and bridge end protection;
- Restore the cross slope to 1.5% if the existing cross slope is flatter than 1.5%; and

- Remove the rigid top rail and brace rails and retrofit with a tension wire design. (WSDOT, 2010)

Safety improvements other than "Basic Safety" items to be combined with resurfacing projects, when appropriate, are, also, identified. These improvements include:

- Spot safety enhancements;
- Channelization;
- Roadside safety hardware;
- Utility objects; and
- Addition of traffic signal control, illumination, and ITS equipment. (WSDOT, 2010).

The pavement resurfacing projects and the "Basic Safety" items in WSDOT are primarily funded by the Pavement Preservation funds. For the two-year period from 2003 to 2005, while a major portion of the Pavement Preservation funds were used for resurfacing, approximately 12 percent of the Pavement Preservation funds in WSDOT were expended on "Basic Safety" items. Safety Improvement funds in WSDOT, on the other hand, are the main funding source for safety improvements beyond "Basic Safety" items and are installed based on a corridor or an area basis. Safety Improvement funds are normally not used for resurfacing projects (Mahoney et al., 2006).

2.2 Selection and Prioritization of Safety Improvements in 3R Projects

In most state DOTs, safety improvements considered in 3R projects are prioritized using the benefit-cost analysis method (Harwood et al., 2003). This section reviews the benefit-cost analysis method with a focus on the benefits and costs considered in the analysis.

2.2.1 Benefit-Cost Analysis

Benefit-cost analysis is used by many state DOTs to select and prioritize safety improvements projects. Two of the most commonly used benefit-cost analysis methods are the benefit-cost ratio and the net value. The benefit-cost ratio for each alternative is obtained using the total benefits divided by the total costs. A benefit-cost ratio greater than 1.0 indicates the considered alternative is feasible. The net value, on the other hand, is computed using the total benefits minus the total costs. The net values of different alternatives can be directly compared to identify the best alternative that typically is the one with the highest net value. In general, if the net value is greater than 0, the corresponding alternative is feasible (Harwood et al., 2003).

Determining the benefits and costs are the fundamentals of the benefit-cost analysis to select and prioritize safety improvement alternatives, therefore, the benefits and costs considered in the practices are reviewed in the following subsections.

2.2.2 Benefits

The benefits of safety improvements often refer to the reduction in fatality, injury, and property damage costs, which are calculated using the unit cost of fatality, injury, or property damage multiplied by the crash reduction factor (CRF), i.e., the percentage of expected reduction in crashes resulting from the installation of safety improvements. These costs may be defined differently among states. For example, IADOT considers the costs of a fatality, major injury, minor injury, and possible injury and property damage as $1,000,000, $150,000, $10,000, $2,500, respectively (IADOT, 2001); however, GDOT uses $5,800,000, $333,500, and $4,400 as the fatality, injury, and property damage costs (GDOT, 2005).

In addition, as indicated in some studies, vehicle speed is expected to increase in a short period right after the completion of resurfacing projects. Therefore, the travel time in this period will decrease and the saving from travel time can be considered as traffic-operational benefits (Harwood et al., 2003).

2.2.3 Costs

Typically, initial installation costs and the maintenance/operation costs are considered as the costs of implementing a safety improvement in the benefit-cost analysis.

While the crash reduction benefits and installation/maintenance/operation costs of safety improvements can be well-defined; there are no direct benefits or costs for the do-nothing alternative. Hence, a penalty for not resurfacing a roadway segment for a specific number of years (until complete replacement is required) is defined as the present value of the future pavement replacement cost (Harwood et al., 2003).

In addition to the penalty for the do-nothing alternative, the Resurfacing Safety Resource Allocation Program (RSRAP) also considers the penalty to be assigned to resurfacing projects without geometric improvements for each improvement alternative (Harwood et al., 2003). The primary concept of this is based on research conducted by Hauer, Terry, and Griffith (Hauer et al., 1994) that indicates resurfacing without accompanying geometric improvements may result in a short-term (approximately 12 to 30 months) increase in accident experience.

2.3 Summary

This chapter first reviews several state DOTs' practices for incorporating safety improvements into 3R projects and summarizes the selection and prioritization of safety improvements using benefit-cost analysis in 3R projects.

In general, 3R projects may include geometric improvements, e.g., pavement widening and culvert extensions. These improvements are often planned and programmed at the design stage of project and, typically, require a longer time to accomplish (e.g., 2 years or more, as indicated by PennDOT). Therefore, there are sufficient time and resource for incorporating safety into 3R projects. Resurfacing projects, on the other hand, are typically operated at a fast pace without the design process. With a tight programming schedule, it is challenging to incorporate additional activities, such as safety improvements, into the resurfacing program. Therefore, it is important to develop an enhanced resurfacing program that can incorporate safety improvements into resurfacing projects and avoid interference to the current operations. The findings are summarized below:

1) Most state DOTs have developed guidelines for incorporating safety improvements into 3R projects. The time required for incorporating safety into 3R projects is generally long because of the nature of safety improvements (e.g., geometric improvements) mentioned above. Incorporating safety improvements into 3R projects also requires more funding sources and more office coordination efforts than resurfacing projects. Therefore, most state DOTs consider incorporating safety improvements at the design or early scoping stages of 3R projects in order to have enough time and source for the incorporation.
2) While 3R projects are funded by pavement preservation funds, safety improvements in 3R projects, on the other hand, are usually funded by the highway safety funds. However, several state DOTs (e.g., WSDOT, CDOT, and ODOT) share a good practice that allows a limited portion (e.g., approximately 6% to 12%) of the pavement preservation funds to be used on essential safety improvements (e.g., Basic Safety items) that are incorporated in the projects.
3) Although resource allocation programs (e.g., RSRAP) or other optimization programs may be in place to prioritize safety improvements in 3R projects, pavement conditions data is still the dominant factor for state DOTs to select 3R projects (Harwood et al., 2003). There is a need to systematically consider safety, in addition to pavement conditions, in the selection process of 3R projects.
4) Because of the differences between various safety improvements by their nature, some state DOTs share a good practice that is to divide safety improvements into different categories (e.g., Basic Safety items in WSDOT, pavement and non-pavement works in NYSDOT) to identify adequate improvements that can be incorporated into resurfacing projects.
5) While many states have published guidelines or design manuals to consider safety in 3R projects, no program is identified in the literature to specify the integration of safety improvements in resurfacing projects. Resurfacing projects, different than 3R projects, often are accomplished at a fast pace and, therefore, allow limited time to prepare the package. Systematically considering safety in resurfacing projects is, thus, more challenging than in 3R projects.

3 GDOT’s Resurfacing Program

To develop a program that can effectively incorporate safety improvements into GDOT’s resurfacing program, in addition to other state DOTs’ practices, the Georgia Tech research team also reviewed GDOT’s current practices for the resurfacing program. This chapter first presents an overview of GDOT’s resurfacing program, including its history, goals, and funding levels, followed by detailed programming steps, including pavement condition evaluation, project selection and prioritization, budget allocation, and let package preparation.

3.1 Overview of GDOT’s Resurfacing Program

GDOT’s resurfacing program, a major component of its pavement preservation program, includes replacement of the surface lift of dense-grade asphalt or an open-graded friction course (if present) not to exceed three inches (GDOT, 2011). This resurfacing program began approximately 30 years ago at the insistence of a Commissioner who reported that Georgia had the worst roads in the Southeast (Tsai et al., 2006). At that time, GDOT made a commitment to perform resurfacing on 10% of the roadways each year so that the entire network would be resurfaced every 10 years. To date, resurfacing 10% (or maintaining an overall rating of 80) of the 18,000 centerline miles state-maintained roadways remains GDOT's goal, despite the budget shortages that have made the goal unachievable.

GDOT’s resurfacing program is operated by the Office of Maintenance with an approximate annual budget of $200 million, which is subject to change from year to year. In fiscal year 2010, a total of $300 million in resurfacing projects were let (with a considerable portion on the interstates). With the funding shortages in recent years, GDOT has experienced an increasing number of deferred resurfacing projects, with some projects delayed up to 3 years (Wang et al., 2009; Wang et al., 2011). There is much concern about that pavement deficiencies, such as friction loss and raveling, in deferred projects may raise safety issues, including hydroplaning, skidding, and loss of control (Zimmerman and Larson, 2005), and put the general public at risk.

Currently, there are limited safety requirements for the resurfacing projects. Table 3.1 summarizes the geometric and safety guidelines for different types of pavement preservation projects, including pavement resurfacing. The resurfacing program in Georgia is a collaborative decision among the General, District, and Area Offices. There are seven working districts in Georgia, i.e., seven District Offices, and each of them manages five to seven Area Offices. GDOT and the Georgia Tech research team have developed and implemented the Georgia Pavement Management System (GPAM) to track pavement conditions and facilitate the decision-making process of pavement preservation and the communication among different offices (Tsai et al., 1998; Tsai and Lai, 2001; Tsai et al., 2002; Tsai and Lai, 2002; Tsai et al., 2008). The Geographic Information System (GIS) functionality is incorporated into the GPAM GIS module to provide an interactive map-based analysis for the multi-year project selection and prioritization (Tsai et al., 2000; Tsai et al., 2004; Tsai and Gratton, 2004; Gao et al., 2006).

Table 3.1 GDOT's Geometric and Safety Guidelines for Preventive Maintenance, 3R, and Reconstruction Projects (GDOT, 2011)

Classification	Type of Work	Design Standards	Upgrade Guardrail if not meeting:	Update Cross Slope and SE	Design Exception Approval
National Highway System (NHS)					
Interstate	Reconstruction and 3R	AASHTO *Green Book* / Interstate Stds.	NCHRP 350	Yes	FHWA
	PM	n/a	NCHRP 350	If crash history warrants	n/a
Freeway Non-Interstate	Reconstruction and 3R	AASHTO *Green Book*	NCHRP 350	Yes	GDOT
	PM	n/a	NCHRP 350	If crash history warrants	n/a
Non-Freeway	Reconstruction	AASHTO *Green Book*	NCHRP 350	Yes	GDOT
	3R	GDOT 3R Standards (1)	NCHRP 230	Yes	GDOT
	PM	n/a	NCHRP 230 (2)	Not required	n/a
Non-NHS					
Non-NHS All Roads	Reconstruction	AASHTO *Green Book*	NCHRP 350	Yes	GDOT
	3R	GDOT 3R Standards (1)	NCHRP 230	Yes	GDOT
	PM – State Route	n/a	NCHRP 230	Not required	n/a
	PM – LARP Work	n/a	Not Required	Not required	n/a

Notes:
(1) Per AASHTO *Green Book*, as amended by this Manual, **Section 11.1.2**. and **Section 11.1.3.**
(2) Upgrade existing guardrail and end terminals, if not meeting referenced standards
Source: Transportation Research Board (TRB), National Cooperative Highway Research Program.

3.2 Procedures for GDOT's Resurfacing Program

This section presents the detailed procedure for developing a resurfacing program in GDOT. Operated by the Office of Maintenance, the resurfacing program is a collaborative decision among different offices (General, District, and Area Offices), and run on a yearly basis with a tight programming schedule. Figure 3.1 shows the detailed steps for developing a resurfacing program and the offices involved in each step. The process starts with a training on the pavement condition evaluation system (PACES) in September each year (GDOT, 1990). The PACES survey is conducted on the entire 18,000 centerline miles roadways between September and December (the off-construction season) to minimize the employment of additional resources. The District Offices are then responsible for selecting and prioritizing the projects requiring resurfacing by March. Finally, the General Office allocates the budget and finalizes a state-wide resurfacing program in May so that resurfacing project letting can take place in July, which is the beginning of a fiscal year (Tsai et al., 2008). Resurfacing projects are let throughout the fiscal year based on the budget schedule. Each of the following steps, as shown in Figure 3.1, is further discussed in this section:

Step 1: Annual Pavement Condition Evaluation Training
Step 2: Annual Pavement Condition Evaluation by Area Offices
Step 3: Annual Pavement Condition Evaluation by District Offices and General Office
Step 4: Project Selection and Prioritization by District Offices
Step 5: Budge Allocation by General Office
Step 6: Field Plan Review by Area Offices and District Offices
Step 7: Let Package Preparation and Environmental Study
Step 8: Pavement Resurfacing Projects Letting

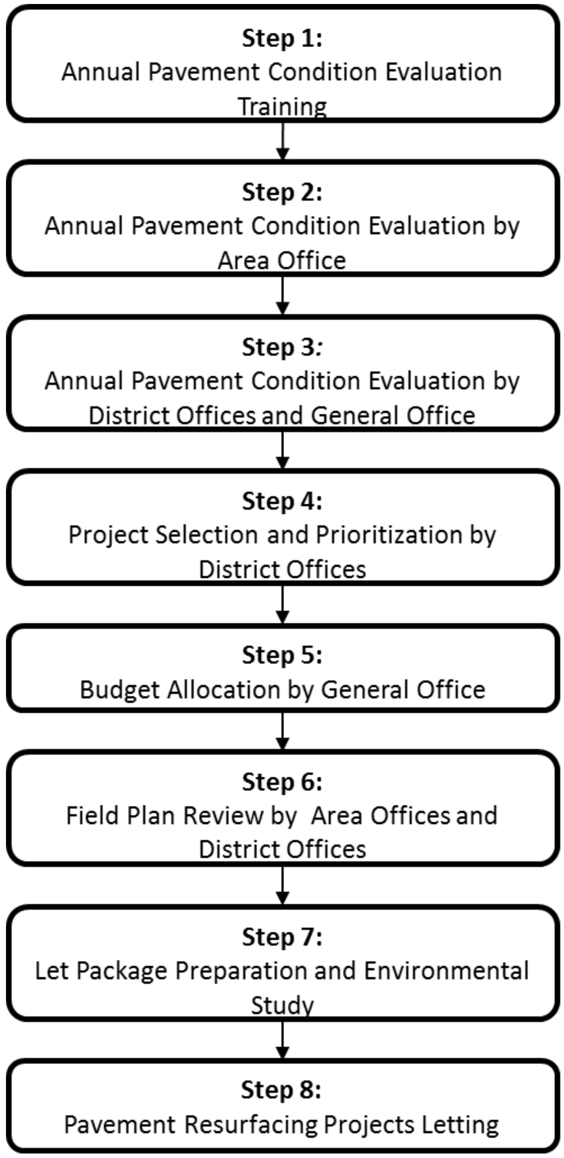


Figure 3.1 Procedures for GDOT's Resurfacing Program

Step 1: Annual Pavement Condition Evaluation Training

GDOT has performed asphalt pavement condition evaluations annually since 1983 using the PACES (GDOT, 1990) developed by GDOT to identify pavement resurfacing needs. The PACES training is conducted by the Office of Maintenance annually for personnel participating in the PACES survey to ensure the quality and integrity of the collected data. The PACES was designed to identify the severity and extent of various types of asphalt pavement surface distresses at the time of the survey. The system standardizes the terminology for the types of distresses that can be found on asphalt pavements in Georgia and defines various levels of severity for each type of distress. The types of distresses include load cracking, block/transverse cracking, rutting, raveling, reflective cracking, loss of section, bleeding/flushing, corrugation/pushing, edge distress, and patches and potholes (GDOT, 1990). Some types of distresses are not recorded in PACES because they either occur infrequently or are included in one of the types listed above at a certain severity level. For example, transverse cracking is considered to be an initial stage of block cracking and is, therefore, rated in that category (Tsai and Lai, 2001).

The PACES adopts three levels of spatial units in managing the data: a project, a segment, and a sampling section. A project, usually several miles long (e.g., 10 miles), is defined using a linear reference system that consists of route type, route number, county code, route suffix, and milepoint from and to. A project is further divided into 1-mile segments for the survey purpose. In surveying cracking distresses, a representative 100-ft sample section is selected within each segment by the rater during the field survey. Results of the distress survey of the 100-ft sample section represent the averaged distress conditions of that 1-mile segment. The distresses recorded for all the segments are then averaged to obtain the representative pavement condition of that project. A project rating (on a scale of 0 to 100) is computed from deduct values which are established for each distress based on the extent and severity level. A rating of 100 represents the project is in excellent condition without any deduct values from any distresses. Table 3.2 and Figure 3.2 show examples of the deduct values for rut and load cracking.

Table 3.2 Deduct Values for Rut

Rutting Extent (inches)							
	0	1/8	1/4	3/8	1/2	5/8	3/4
Deducts	0	2	5	12	16	20	24

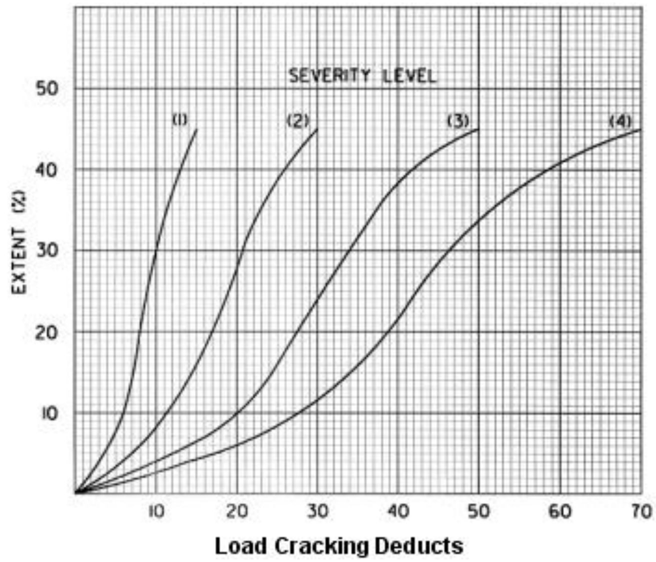


Figure 3.2 Deduct Values for Load Cracking

Step 2: Annual Pavement Condition Evaluation by Area Offices

The Area Offices conduct the PACES survey annually from September to December on all the routes they are responsible for, which in fact cover the entire 18,000 centerline miles of state-maintained highways. A Computerized Pavement Condition Evaluation System (COPACES), which is a paperless field data collection system implemented in 1998, has been used by GDOT to facilitate the data collection process and ensure the data quality and integrity (Tsai and Lai, 2001; Tsai and Lai, 2002). Figure 3.3 shows the inputs at both project and segment level, which are cross-checked to ensure the data quality and integrity.

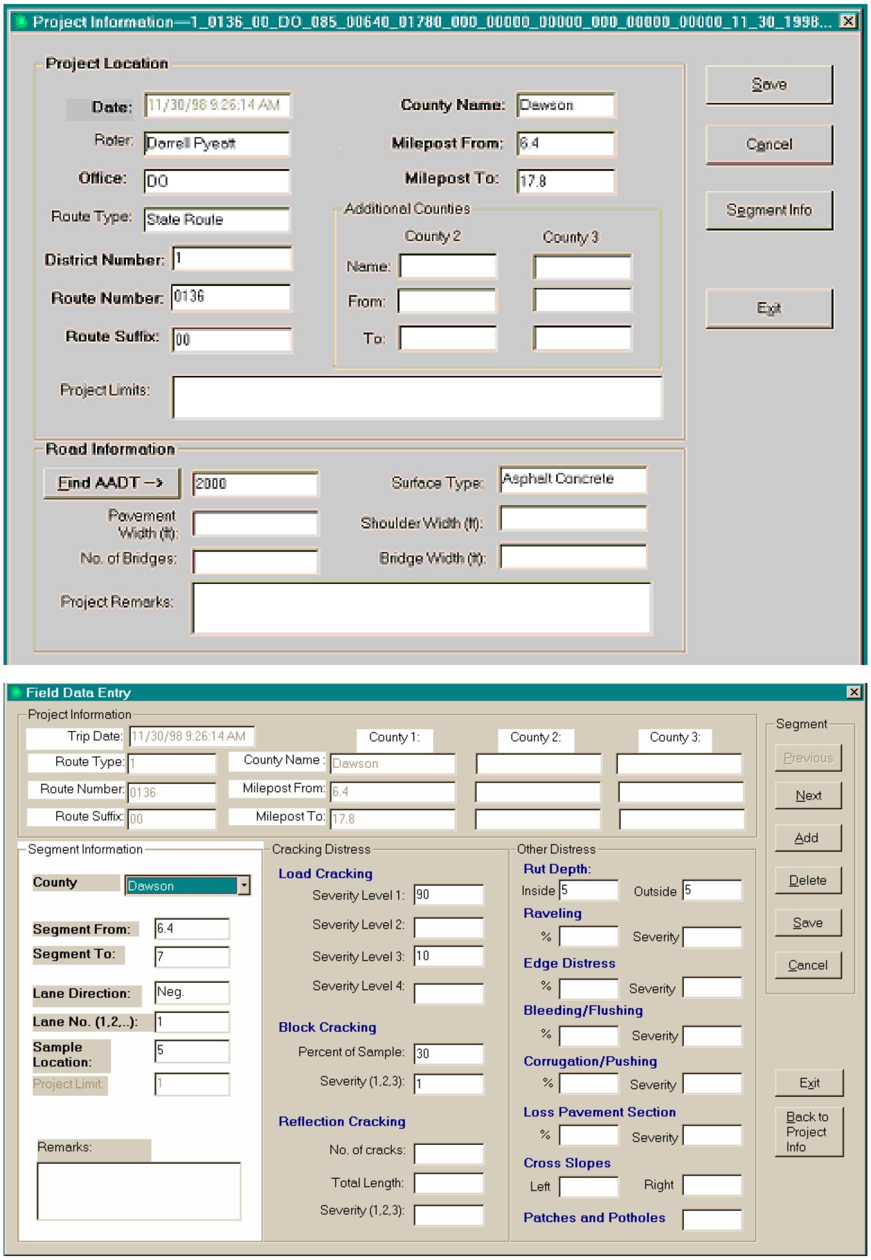


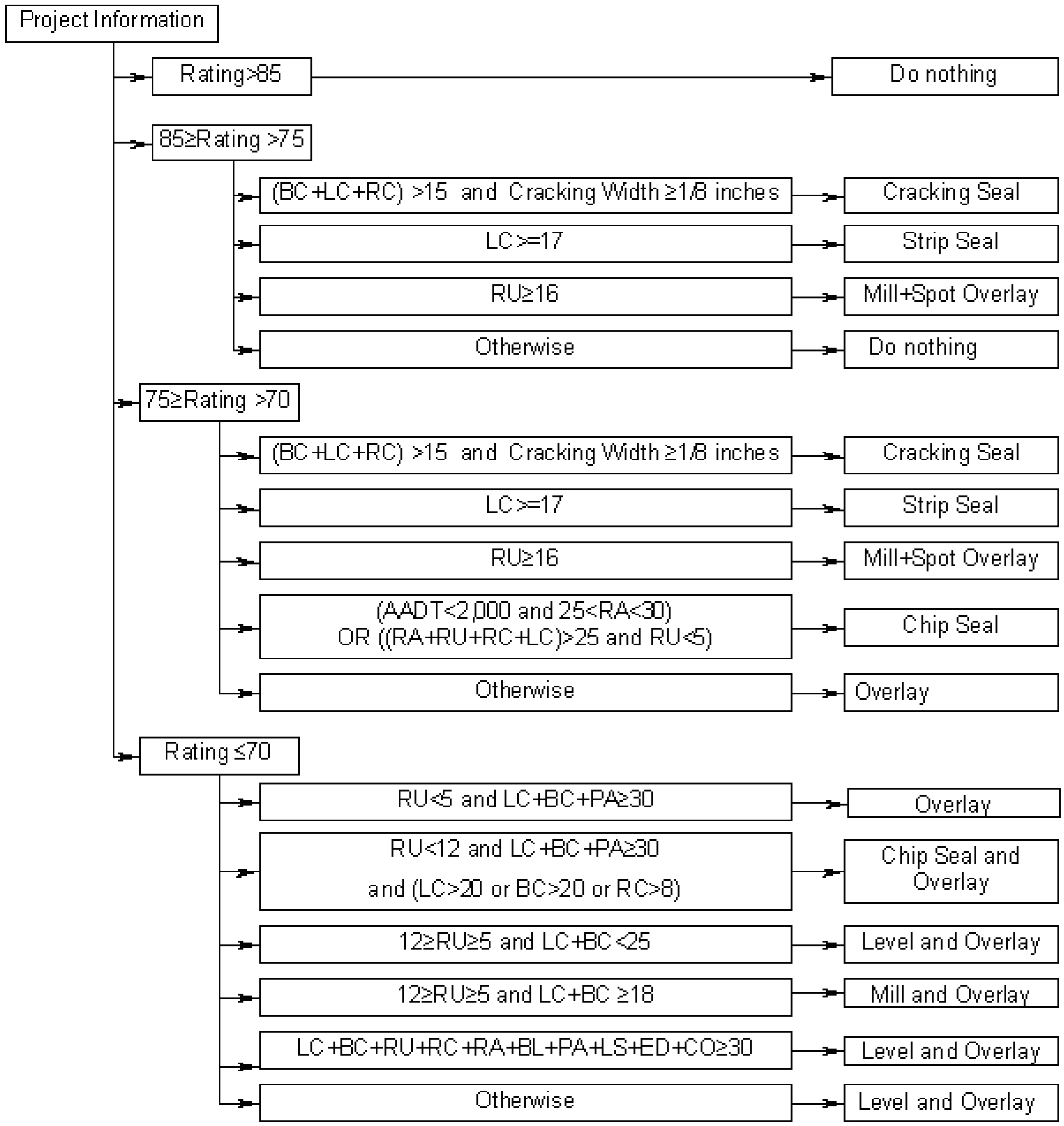
Figure 3.3 Field Data Entry (Project-Level and Segment-Level) in COPACES

Step 3: Annual Pavement Condition Evaluation by District Offices and General Office

The District Offices and General Office conduct the PACES survey again on resurfacing project candidates, which are the projects with a PACES rating equal to or less than 75 according to Area Offices' survey. This step is to seek concurrence on whether or not the pavement condition warrants resurfacing, and the decision on resurfacing is based on the PACES survey conducted by District and General Office.

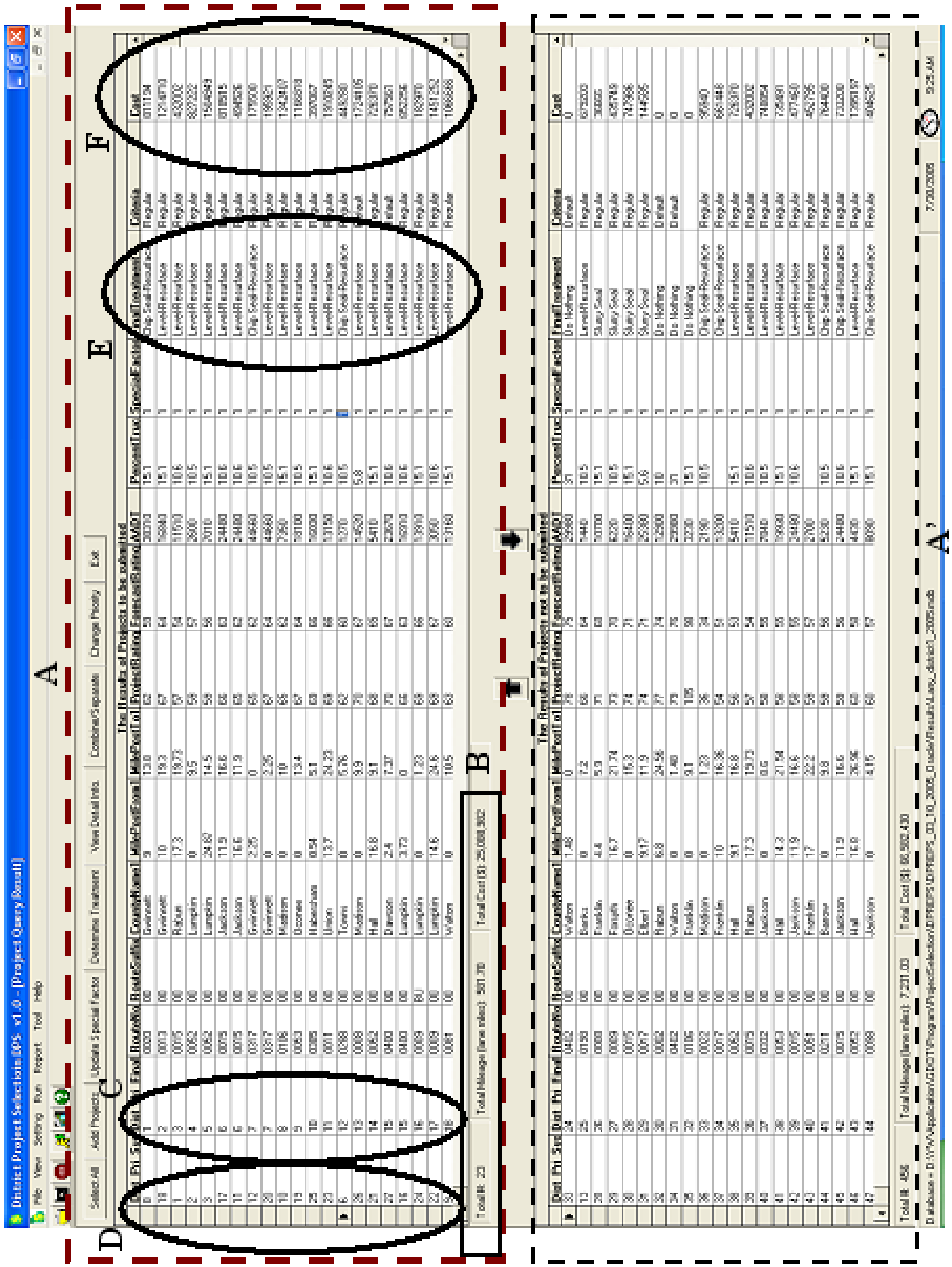
Step 4: Project Selection and Prioritization by District Offices

Each District Office is responsible for selecting and prioritizing the projects in need of resurfacing within the district. A District Project Selection (DPS) program has been implemented by GDOT since 2000 to facilitate this decision-making process (Tsai et al., 2002; Tsai et al., 2008). The DPS program supports the determination of proper treatment method for each project according to GDOT's treatment criteria, which consider rating, type of distress, and deduct values. An example of the treatment criteria is shown in Figure 3.4. The cost of each resurfacing project is also estimated using treatment unit cost and roadway characteristics data (e.g., pavement width), as shown in Figure 3.5. Resurfacing projects can then be prioritized based on pavement conditions (mainly the PACES rating), as well as user-specified factors, such as traffic volume (AADT & truck percent) and special concerns (e.g., safety). The DSP program also allows District Offices to effectively review the detailed distress condition and historical pavement condition data for each project, as shown in Figure 3.6, which is very crucial for determining the treatment method. In addition, the engineers will make the final decision on the treatment method and the project priority based on their expertise and understanding of the local roadway condition. The final resurfacing treatment method is determined based on engineer's experience and pavement design guidelines developed by the Office of Materials and Research. If engineers determine there are unusual pavement distresses on the roadways, a detailed laboratory analysis will be performed and a recommendation on the treatment method will be given by the Office of Materials and Research. The DSP program provides the flexibility for engineers to make any necessary modification on the project priority, treatment method, and treatment cost. Finally, District Offices will submit the final project list to the General Office through the DSP program.



BC: Blocking cracking deduct value; LC: Load cracking deduct value;
RC: Reflective cracking deduct value; RA: Raveling deduct value; RU: Rutting deduct value

Figure 3.4 GDOT's Treatment Criteria



Note: 1 mile = 1.61 km

Figure 3.5 Example of Project Selection and Prioritization in GPAM

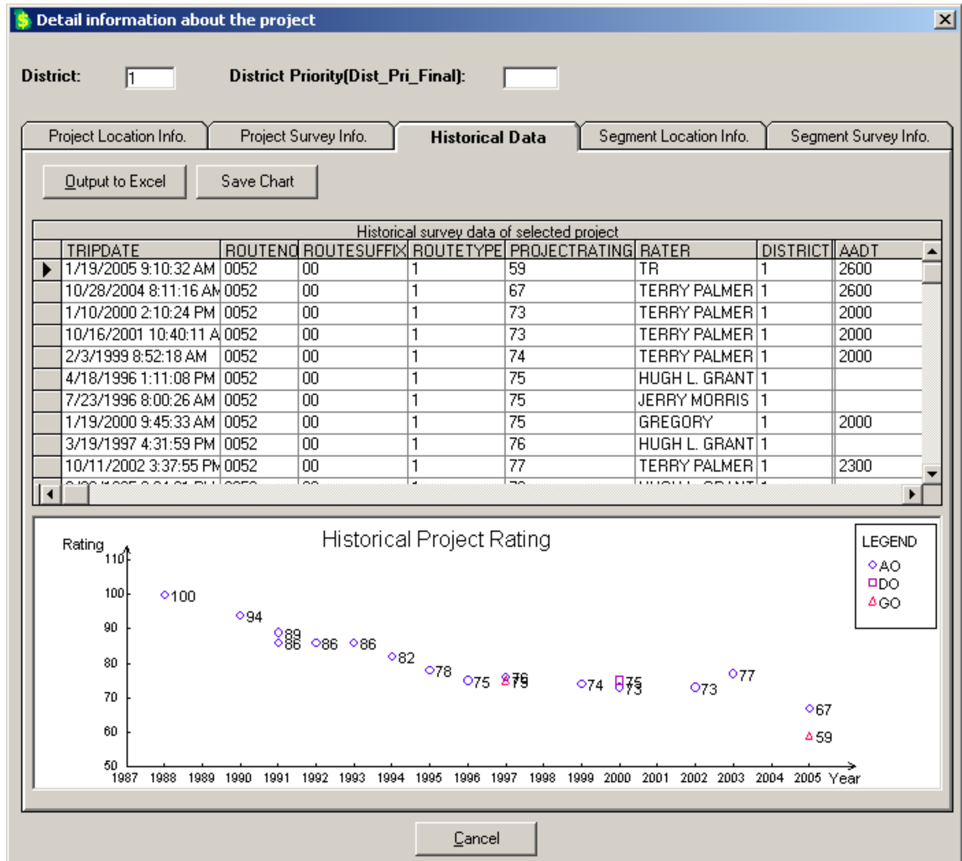


Figure 3.6 Pavement Condition History in GPAM

Step 5: Budget Allocation by General Office

The General Office compiles all the lists from seven District Offices annually and finalizes the statewide pavement resurfacing projects based on budget availability, long-term effectiveness, and other requirements, as illustrated in Figure 3.7. A General Office Project Selection (GOPS) program has been implemented to assist the General Office on prioritizing the statewide resurfacing projects based on various criteria, such as workload balance among working districts or congressional districts, performance balance among working districts or congressional districts, worst-first, and funding balance based on centerline miles (Tsai et al., 2002; Tsai et al., 2008), as shown in Figure 3.8. After the district priority and statewide funding constraints are taken into account, the list of resurfacing projects can be finalized. The GOPS program also allows the General Office to make any necessary modification on the project priority, treatment method, and treatment cost.

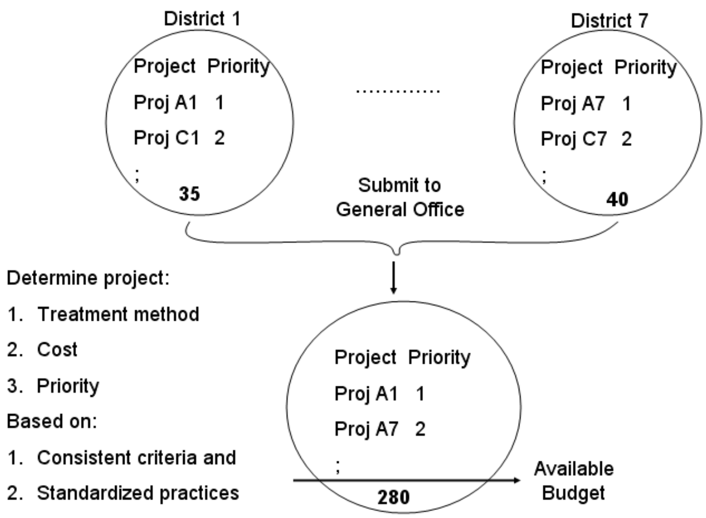


Figure 3.7 General Office Finalizes the Projects Based on Constraint

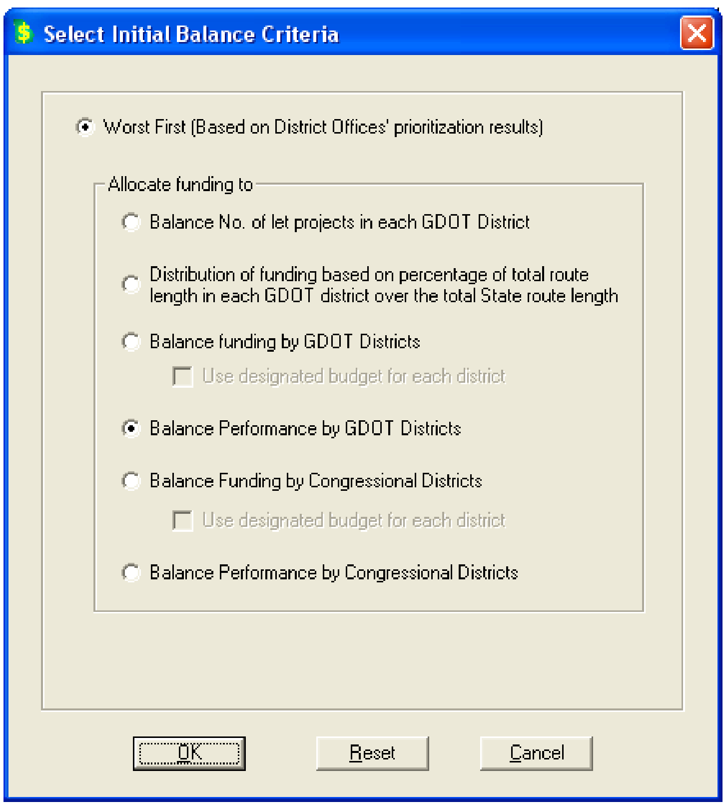


Figure 3.8 Statewide Funding Distribution and Project Selection Criteria

Step 6: Field Plan Review by Area Offices and District Offices

Once the General Office finalizes resurfacing program for the fiscal year, the District Offices are advised to conduct field plan review for each resurfacing project in order to collect detailed information to finalize the works and associated costs to be included in the let package. During the field plan review, accident data may be obtained to determine if additional safety improvements (e.g., rumble strips) can be included in the pavement resurfacing project. For some projects, traffic operation engineers may provide recommendations on the safety improvements.

Step 7: Let Package Preparation and Environmental Study

The General Office compiles all the data from the District Offices and formats all necessary information, such as the environmental study if needed, into documents that are submitted to the Office of Contract Bidding Administration to complete the package and let the contract. Currently, a typical resurfacing project, including shoulder build, does not require an environmental study, and an approval can be obtained within a few months. The let package is usually prepared four months in advance of the scheduled letting of the project. The final package includes cover sheet, index, location sketch, typical section, roadway log, detailed estimate, general notes, erosion control plan, and construction details when applicable.

Step 8: Pavement Resurfacing Projects Letting

With the budget allocated and the let packages prepared, pavement resurfacing projects are put out for bidding. The Office of Contract Bidding Administration advertises the project (usually for one month) and the bids are opened to prequalified contractors. The project will be awarded to the lowest reliable bidder whose proposal meets all the prescribed requirements.

3.3 Summary

GDOT’s resurfacing program is operated at a fast pace with limited funding to extend the pavement life cost-effectively. With severe funding shortages in recent years, GDOT has experienced an increasing number of deferred resurfacing projects. There is much concern that pavement deficiencies, such as friction loss and raveling, in deferred projects could raise safety concerns, including hydroplaning, skidding, and loss of control (Zimmerman and Larson, 2005), and, consequently, put the general public at risk.

The decisions on GDOT's pavement resurfacing projects, including treatment methods and selection and prioritization of resurfacing projects, are mainly based on pavement conditions, i.e., the PACES rating. Although engineers have the flexibility to include certain safety improvements and adjust a project's priority, the decision heavily relies on engineers' judgments. There is a need to develop a systematic approach within the resurfacing program to assist engineers in addressing safety improvements throughout the decision-making process. Also, the data to support safety concerns identification is not available in the pavement management system (i.e., GPAM).

The "fast pace" characteristic of GDOT's resurfacing program also makes it challenging to incorporate safety improvements into the resurfacing program. A resurfacing project, which typically does not require an environmental study under current regulations, can be programmed (including the PACES survey, project selection, budget allocation, and let package preparation) within a few months. Safety improvements, on the other hand, typically require an environmental study that may take from a few months to 2 years depending on the type of safety improvement.

In summary, an enhanced, safety-incorporated resurfacing program is needed to assist the engineers in effectively and systematically incorporating safety improvements into GDOT's current fast-paced resurfacing program without interfering the programming process.

4 GDOT's Safety Improvement Program

This chapter presents a review of Georgia's safety improvement program with a focus on the program initiatives that address engineering solutions. First, a brief overview of Georgia's Strategic Highway Safety Plan (SHSP), including the goals, the key emphasis areas, and the program initiatives, is presented. Second, the process adopted by the Office of Traffic Operations for identifying site improvements and system-wide improvements is described.

4.1 Overview of Georgia's Strategic Highway Safety Plan

Georgia's SHSP, developed with the requirements of the Safe, Accountable Flexible and Efficient Transportation Equity Act-A Legacy for Users (SAFETEA-LU), identifies the goals for Georgia's safety improvements, the key emphasis areas, and the implementation plan, which encompasses the four "E" components, i.e., engineering, enforcement, education, and emergency medical services to achieve its safety goals (GOHS, 2010).

Georgia's SHSP goal of achieving zero deaths or injuries by reducing crash deaths by at least 4% per year is based on the national safety goal of reducing highway fatalities by 1,000 per year, which was set by the American Association of State Highway and Transportation Official (AASHTO). Since Georgia fatalities contribute approximately 3.9 % to the national fatalities, Georgia would need to reduce highway fatalities by 39 annually to help achieve the national safety goal. The goal of reducing statewide fatalities by 4% is above the 39 fatality target, and results in a goal of 41 fewer fatalities per year (GOHS, 2010). Due to the variation in yearly statewide fatality numbers, safety programs will be evaluated using three-year averages.

To accomplish this goal, the Georgia's SHSP (GOHS, 2010) identifies 10 highway safety emphasis areas as follows:

- Occupant Protection
- Serious Crash Type

- Aggressive Driving/Super Speeder
- Impaired Driver
- Age related issues
- Non-motorized User
- Vehicle Type
- Trauma System/Increasing EMS Capabilities
- Traffic/Crash Records and Data Analysis
- Traffic Incident Management

Program initiatives developed by GDOT to address serious crash types through engineering solutions are as follows (GDOT, 2005):

- Preventing vehicle roadway departures
  - Shoulder rumble strips
  - Centerline rumble strips
- Minimizing consequences of leaving the road
  - Crash impact attenuators
  - Cable barrier systems
- Improve design and operation of intersections
  - Implement the "Intersection Safety Action Plan"
  - Traffic signal compliance
- Pedestrian safety
  - Pedestrian countdown timers program
  - Mid-block crossing program
  - Design accommodations at intersections
- Reduce vehicle/train crashes
- Off-system pilot office support and implementation

4.2 Process for Identifying Site and System-wide Improvements

To achieve the goal of reducing highway crash fatalities by 4% each year with limited funding, GDOT has performed various safety studies to identify engineering solutions that can cost-effectively reduce crashes as well as fatalities. The studies include the analyses of crash trend (Washington et al., 2002; Dixon, 2005; Dixon et al., 2009), site selection methods (Alluri, 2008), strategies for improving work zone safety (Daniel et al., 1995; Wang et al., 2003), etc. This section focuses on two basic types of safety studies performed by the Office of Traffic Operations for identifying site improvements and system-wide improvements.

4.2.1 Site Improvement Study

A site improvement study is a traditional approach to identify, study, and select appropriate safety improvements for the sites/locations with high crash rates (e.g., frequency) and/or fatalities. Based on actual crash data, each year the Office of Traffic Operations generates a list of intersections and sections of roadways, referred as the Top 150, that have a higher-than-average number of vehicle crashes. The detailed steps for selecting site improvements are shown in Figure 4.1, and each step is discussed as follows:

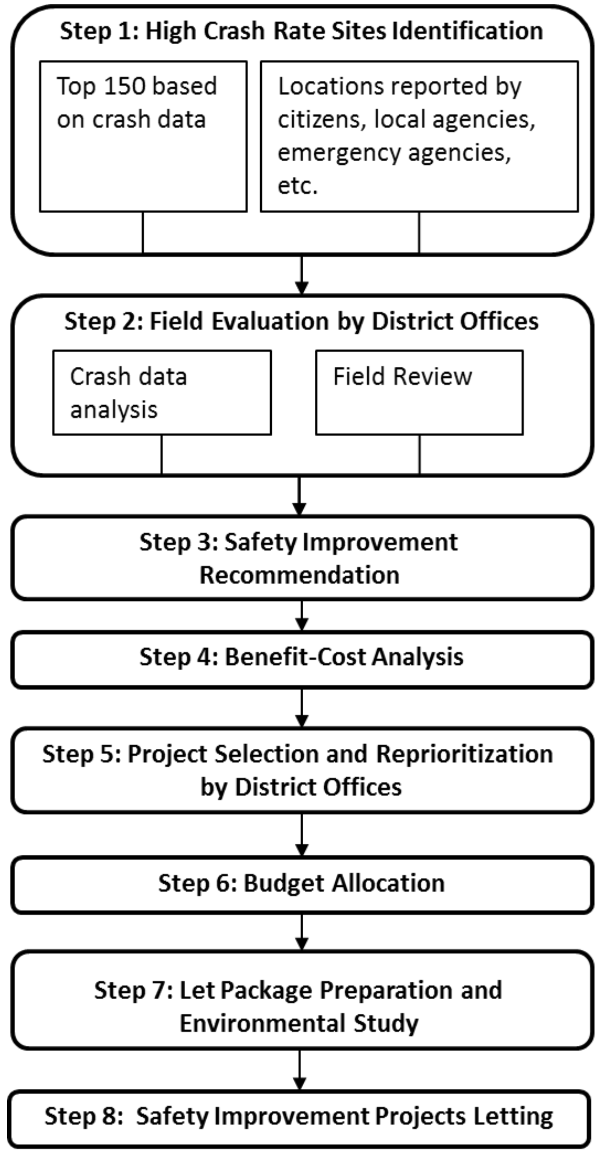


Figure 4.1 Process for Site Improvement

Step 1: High Crash Rate Sites Identification

The sites with safety improvement potential are identified in different ways. One of the common ways is to analyze crash data to identify sites with a higher accident frequency and/or fatalities. Each year, the Office of Traffic Operations generates a Top 150 Sections and Intersections Report that ranks the sites with highest improvement potential (GDOT, 2006). The Top 150 list is generated based on a rate quality-controlled method described in the report "Evaluation of Criteria for Safety Improvements on the Highway" (Jorgensen, 1966). A statistical test is used to determine if the crash rate at a particular site is abnormally high in comparison to the crash rate of locations with similar roadway characteristics. Roadways are grouped by type and characteristics (e.g., rural 2-lane roads) for a reasonable comparison. For example, interstates are compared with interstates and four-lane urban roads are compared to other four-lane urban roads. A review of GDOT's Top 150 method is described in Appendix III. In addition to the Top 150, the locations reported by citizens, elected officials, local governments, city and county engineers, emergency agencies, and metropolitan planning organizations are also considered as candidate sites.

Step 2: Field Evaluation by District Offices

The list of sites identified in Step 1 is distributed to the District Offices for a field evaluation, which includes crash data analysis and a field survey to diagnose the nature of safety problems at specific sites.

Step 3: Safety Improvements Recommendation

Proper action will be recommended based on the field evaluation and GDOT's design guidelines. According to the Plan Development Process (GDOT, 2000), "*an action can be recommended because of a positive impact on an existing safety problem, because of evidence that it will prevent a hazardous condition, or because it may fall into one of several pre-approved categories of improvements that are known to provide safety benefits*." Examples of the pre-approved improvements include guardrail, traffic signals, railroad crossing warning devices, and most intersection improvements. Currently, sites are being reviewed by consultants, in-house engineers, and District Offices.

Step 4: Benefit-Cost Analysis

A benefit-cost analysis is performed for each site improvement project. For each candidate project, the costs, including right-of-way (ROW), utilities, construction, and operations are evaluated against the projected benefits from reduced property damages, injuries, and fatalities. Crash reduction factors (CRF) provided by NCHRP are used in the analysis.

Step 5: Project Selection and Prioritization by District Offices

The projects are then prioritized based on the benefit-cost analysis.

Step 6: Budget Allocation

The Office of Traffic Operations allocates the budget based on factors such as benefit-cost ratio, districts, and funding availability.

Step 7: Let Package Preparation and Environmental Study

The Office of Traffic Operations compiles all the data from the District Offices and formats the information into documents submitted to the Office of Contract Bidding Administration, which completes the package for letting the contract. The required formal approval, documentation, and environmental study for each project follow the normal Plan Development Process. The time needed for developing a safety improvement project varies significantly from a few months to 2 years, depending on the types of safety improvements. For example, lane widening and realignment may require 8 to 24 months for the environmental study, while adding a left turn lane can take 6 months.

Step 8: Safety Improvement Projects Letting

With the budget allocated and the let packages prepared, safety improvement projects are put out to bid year round. The Office of Contract Bidding Administration will advertise the project (usually for one month) and the bids are opened to prequalified contractors. The project will be awarded to the lowest reliable bidder whose proposal meets all the prescribed requirements.

4.2.2 System-wide Safety Improvement Study

The system-wide safety improvement study provides a systematic approach to deploy low-cost safety improvements at a larger number of locations with the potential for a certain types of crashes. Figure 4.2 shows the detailed steps for identifying system-wide safety improvement projects.

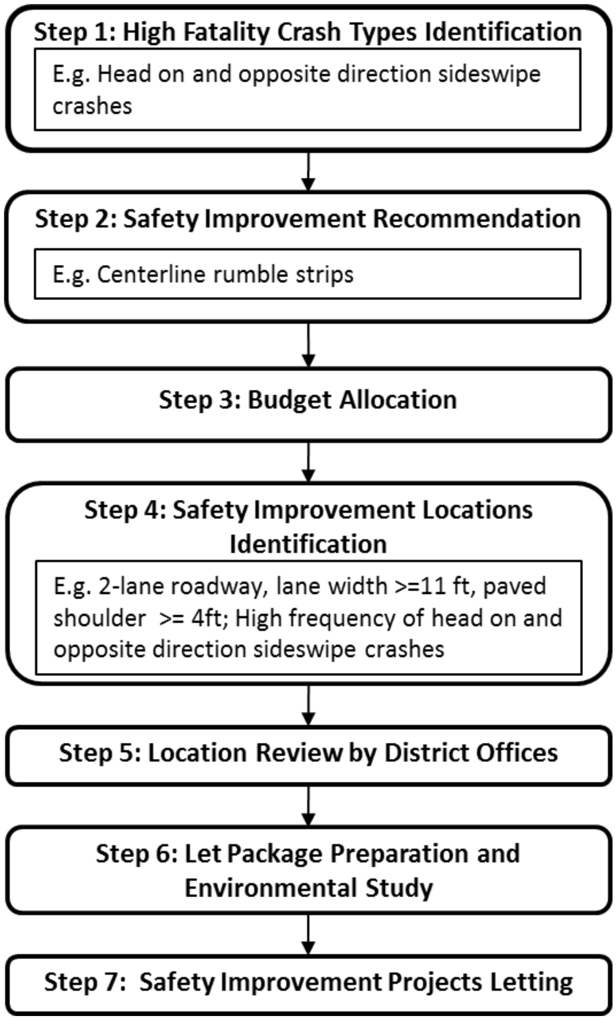


Figure 4.2 Process for System-wide Improvement

Step 1: High Fatality Crash Types Identification

The types of crashes with high fatalities in Georgia are first identified by analyzing crash data. For example, in 2003, head-on and sideswipe opposite direction crashes represented 2% of the total crashes, but accounted for 12% of the total number of fatalities statewide based on the crash data. Thus, safety improvements that could prevent head-on and sideswipe opposite direction could be implemented statewide.

Step 2: Safety Improvements Recommendation

Safety improvements are then recommended for selected high-fatality crash types based on the national-level and/or GDOT's studies.

Step 3: Budget Allocation

The budget is allocated for each safety improvement based on the damages, injuries, and fatalities that can be reduced by adapting the safety improvement. Given the allocated budget, the quantity (e.g., miles to treat) can be determined by dividing the allocated budget by the unit cost of the safety improvement.

Step 4: Safety Improvement Locations Identification

The Office of Traffic Operation uses both roadway characteristics and crash data to identify the locations that are suitable for the safety improvement. For example, two-lane roadways with a lane width greater than 11 ft. and a shoulder greater than 4 ft. can be identified for centerline rumble strips if head-on and sideswipe opposite direction crashes occur more often at the location.

Step 5: Location Review by District Offices

The list of locations is distributed to the District Offices for review. The list is then finalized after incorporating the District Offices' inputs.

Step 6: Let Package Preparation and Environmental Study

The process and requirements for preparing a let package are the same as the site improvement project described in Section 4.2.1. Again, the time needed for developing a project varies from a few months to 2 years based on the types of safety improvements.

Step 7: Safety Improvement Projects Letting

See Section 4.2.1 for letting a project.

4.3 Summary

The safety program initiatives implemented by the Office of Traffic Operations are funded by safety funds and developed based on GDOT's normal Plan Development Process. Since safety improvements are by their nature very time sensitive, it is common that they will follow a fast track whenever possible. While most safety projects will be categorically exempt from federal air quality requirements, they will also follow tracks that are appropriate to the types of the improvements. For example, an improvement with a signing change, signal phasing change, or pavement marking change requires little or no formal approval (e.g., environmental study), documentation, or evaluation (other than a follow up to check the crash history). This type of safety improvements can be implemented within a short period of time (within 4 months). Other types of safety improvements, such as adding a turn lane and installing traffic signals, require an environmental study and may take a long period of time (e.g., 12-24 months) to process before being installed. While the safety program initiatives are implemented by the Office of Traffic Operations, the benefits of incorporating safety into the resurfacing program are recognized by both the Office of Traffic Operations and the Office of Maintenance. As indicated in the Safety Action Plan (GDOT, 2005) and the interviews with the two offices, it is more effective in terms of cost and operation to incorporate some safety improvements into the existing resurfacing program. For example, the cost for centerline rumble strips is about $1,000 per centerline mile when incorporated into a resurfacing project but is about $6,000 per centerline mile in a stand-alone project. In addition, the traffic interruption to the general public can be reduced.

5 Proposed Safety-Incorporated Resurfacing Program

Georgia Tech research team has worked closely with GDOT's Office of Maintenance and Office of Traffic Operations to propose an enhanced resurfacing program that can systematically incorporate safety improvements into GDOT's existing fast-paced resurfacing program. This chapter first presents an overview of the proposed safety-incorporated resurfacing program that consists of three components, including safety improvements categorization, safety concerns and roadway upgrade needs identification, and project reprioritization, followed by the detailed description of each component.

5.1 Overview

A safety-incorporated resurfacing program is proposed in this study for GDOT to 1) identify deferred or upcoming resurfacing projects with safety concerns or roadway upgrade needs, 2) reprioritize these projects to minimize potential safety risks, and 3) seamlessly incorporate safety improvements into its existing fast-paced resurfacing program. The proposed safety-incorporated resurfacing program consists of the following three major components:

1) Safety improvements categorization:
   All safety improvements are divided into three categories based on the integration efforts needed for incorporating them into the resurfacing program.
2) Identification of safety concerns and roadway upgrade needs:
   A two-stage approach, including an in-house computerized search and a field evaluation, is proposed to systematically identify potential safety concerns and roadway upgrade needs in deferred and upcoming resurfacing projects.
3) Project reprioritization:
   A project reprioritization method, using a modified PACES rating that takes into account safety concerns, is proposed to prioritize resurfacing projects to minimize potential safety risks.

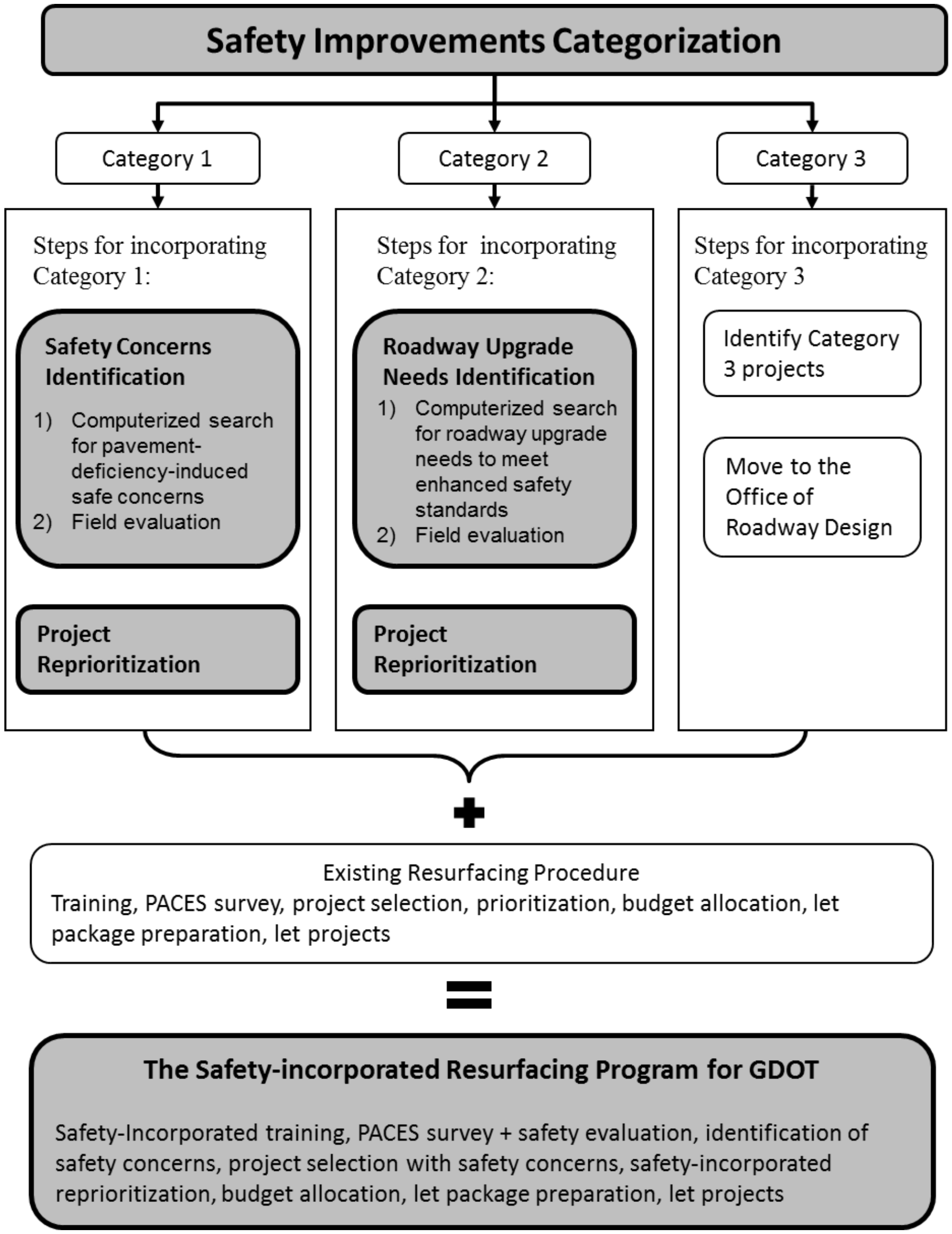


Figure 5.1 Overview of the Proposed Safety-Incorporated Resurfacing Program

5.2 Safety Improvements Categorization

Different safety improvements, such as rumble strips installation, guardrail delineation, traffic sign installation, lane/shoulder widening, etc., may require different implementation times and efforts. While some safety improvements, such as rumble strips and pavement raised markers, can be installed during or right after the resurfacing, other safety improvements, such as lane widening, shoulder widening, etc., may take a longer time due to planning, environmental study, and/or right-of-way acquisition. Therefore, to systematically incorporate safety improvements into the fast-paced pavement resurfacing program, safety improvements are divided into three categories based on the integration efforts in terms of duration, funding sources, and office coordination. Here, duration refers to the time required for GDOT to get approval (if needed) and implement or install the safety improvements; funding sources indicate the primary source(s) of budget for the installation of safety improvements; office coordination includes the required collaboration and coordination among various offices.

Three categories, including 1) resurfacing, 2) safety improvements requiring no environmental studies, and 3) safety improvements requiring environmental studies are discussed in the following subsections. The objective of this categorization is to make the integration of safety into the pavement resurfacing program practically feasible.

5.2.1 Category 1: Resurfacing

This category actually requires no safety improvement installations. The safety concerns in this category include hydroplaning, skidding, and loss of control, which are caused by pavement deficiencies (e.g., deep rutting, frictionless surface, etc.) and can be addressed directly by resurfacing. In other words, the pavement resurfacing itself is the safety improvement. This category typically requires less integration effort because it follows the typical process for developing a resurfacing project and is funded and operated solely by the Office of Maintenance. This category is the highest priority to be incorporated into GDOT’s existing fast-paced resurfacing program.

5.2.2 Category 2: Safety Improvements Requiring No Environmental Studies

This category focuses on safety improvements that require no environmental studies. In other words, the installation of this category of safety improvements does not require additional environmental approval and can be done during or right after the resurfacing. Moreover, the additional costs for improvements in this category are usually not significant compared to the typical resurfacing costs; thus, they can be funded and operated by one or two offices (e.g., Office of Maintenance and/or Office of Traffic Operations). Therefore, it is feasible to incorporate safety improvements in this category into GDOT's fast-paced resurfacing program without major interference to its current practices. Safety improvements in this category include but are not limited to the following:

- Centerline rumble strips/stripes;
- Shoulder rumble strips/stripes;
- Shoulder builds;
- Cross-slope adjustments;
- Superelevation adjustments;
- Installation of guardrails (may require additional funding);
- Installation of median barriers (may require additional funding).

In addition, incorporating safety improvements in this category into the current pavement resurfacing program may provide an opportunity to systematically and cost-effectively upgrade the roadway system to meet enhanced safety standards. As the roadway system is resurfaced approximately in a 10-year cycle, these safety improvements, such as centerline rumble strips, can be implemented to upgrade Georgia's roadway system within the same cycle. Safety improvements in this category may be funded by the Office of Maintenance through a designated percentage of the pavement preservation funds; additional funds may also be set aside by GDOT to leverage the safety-incorporated, fast-paced resurfacing program.

5.2.3 Category 3: Safety Improvements Requiring Environmental Studies

Safety improvements in this category require an environmental study, and, therefore, a longer time is needed for programming the project. The time required for the environmental study usually depends on the type of safety improvements, but it is often longer than 6 months. For example, lane widening and realignment that require additional right of way may need 24 months for the environmental study.

Moreover, as mentioned in the literature, safety improvements in this category are often funded by highway safety funds, whereas resurfacing projects are funded by pavement preservation funds; therefore, the integration of multiple funding sources is needed to incorporate safety improvements in this category into the resurfacing program. More coordination among GDOT's offices (i.e., the Office of Maintenance, the Office of Traffic Operations, the Office of Roadway Design, the Office of Environmental Services, and others) is required to incorporate safety into the resurfacing program at the design stage. The safety improvements in this category include:

- Lane widening;
- Shoulder widening;
- Lane addition (turn lanes, accelerate/decelerate lanes, heavy vehicle climb lanes);
- Major sight distance adjustments (vegetation clearing, object removal from clear zone, etc.);
- Horizontal alignment improvement;
- Vertical alignment improvement;
- Signal addition; and
- Others.

5.3 Identification of Safety Concerns and Roadway Upgrade Needs

A two-stage approach has been proposed to systematically identify the need for Category 1 and Category 2 safety improvements mentioned previously. This approach can address pavement-deficiency-induced safety concerns and upgrade the roadways to meet enhanced safety standards. The two stages are 1) an in-house computerized search based on pavement conditions (e.g., distress type, severity), roadway characteristics (e.g., straight road, curved road) 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. The two-stage approach is discussed in the following subsections.

5.3.1 Identification of Safety Concerns

A two-stage safety concerns identification, as depicted in Figure 5.2, is proposed to systematically identify the pavement-deficiency-induced safety concerns. The two stages, as mentioned previously, are 1) an in-house computerized search based on pavement condition, roadway characteristics, and crash history, and 2) a field evaluation to confirm the safety concerns.

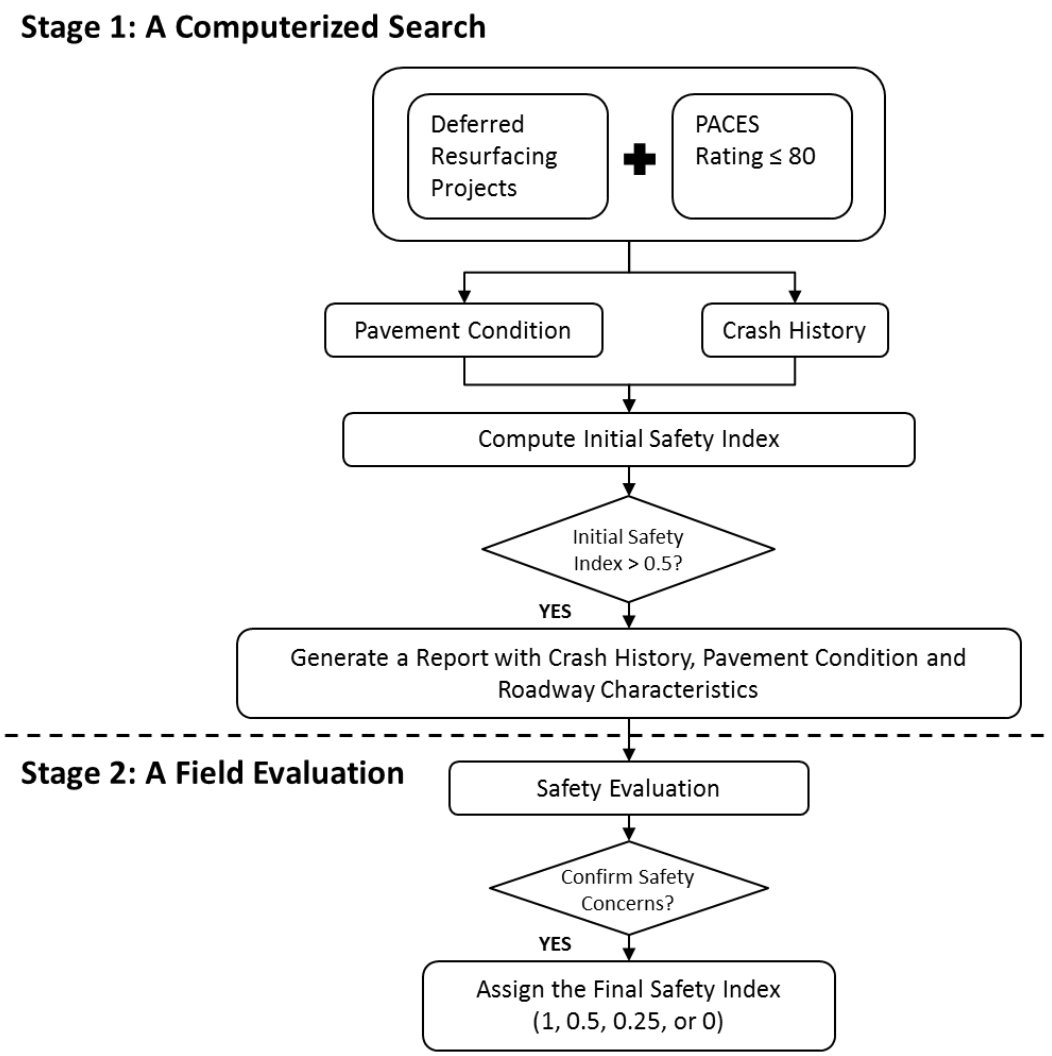


Figure 5.2 Two-Stage Safety Concerns Identification

Both deferred resurfacing projects and upcoming projects with the PACES rating less than or equal to 80 are considered in the safety concerns identification process. First, a computerized search is performed for each project at a segment level to identify specific sites with safety concerns. To be consistent with the PACES survey, the computerized search is based on a 1-mile segment except the beginning or end segment in the project.

Ten safety factors, including accident rate, fatality rate, injury rate, wet pavement accident percentage, number of road defect in accident reports, roadway characteristics, PACES segment rating, difference between project and segment rating, rut depth, and number of potholes/patches, are searched in the GPAM and crash database for each segment. These factors are identified as potential indicators that may lead to pavement-deficiency-induced safety concerns through discussion with the Office of Maintenance and the Office of Traffic Operations. The factors are categorized and given different weighted values based on the level of safety concerns, as shown in Table 5.1. Each segment will be given 10 weighted values for the ten factors, and one-hundredth of the sum of the 10 weighted values is defined as the safety index for the segment. The safety index is on a scale of 0 to 1, with 1 representing the highest level of safety concerns. The segment with the highest safety index in a project is then assigned as the initial safety index for the project. A project that has an initial safety index greater than or equal to 0.5 is recommend for a field safety evaluation, i.e., the second stage of safety concerns identification. Note that the proposed weighted values in Table 5.1 are preliminary results based on the discussion with GDOT and a review of safety countermeasure installation policies (Russell and Rys, 2005). These values (including factor, category and weighted values) may be further refined by the Office of Traffic Operations based on statistical analyses of different road types (e.g., functional classes) in Phase 2.

Table 5.1 Safety Factors and Weighted Values

Segment PACES Rating	Value
80 and more	0
70-79	2
60-69	5
Less than 60	10

PACES Rating Difference between Segment and Project	Value
Less than 5	0
5-8	5
9 and more	10

Rut Depths (in.)	Value
Less than 3/8	0
3/8	5
4/8 and more	10

Number of Patches and Potholes (per yr)	Value
Less than 4	0
4-6	2
7 and more	5

3-yr Accident Rate (accidents/mi/year)	Value
0	0
0.001-1.999	2
2.000-3.999	4
4.000-5.999	6
6.000-7.999	8
8.000 and more	10

3-yr Wet Surface Accident Percentage (%)	Value
0.000-9.999	0
10.000-19.999	2
20.000-29.999	5
30.000 and more	10

3-yr Fatality Rate (deaths/mi/year)	Value
Less than 0.333	0
0.333-0.665	10
0.666-0.999	15
1.000 and more	20

3-yr Injury Rate (injuries/mi/year)	Value
0	0
0.001-0.999	2
1.000-1.999	5
2 and more	8

Number of 3-yr Road Defects	Value
0	0
1	8
2 and more	15

Roadway Characteristics	Value
1 (Straight or Curve and Level)	0
2 (Curve and Grade)	1
3 (Curve and Hill)	2

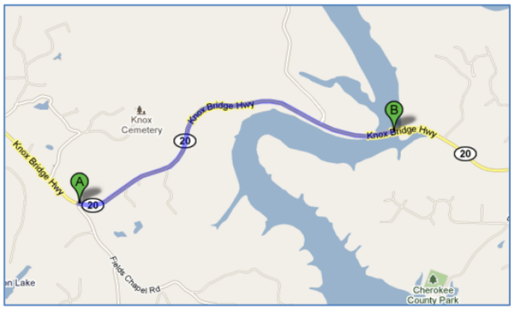
The safety concerns identified through the computerized search in the first stage will be confirmed through a field evaluation if the initial safety index of the project is greater than or equal to 0.5. In order to align the proposed program with the existing resurfacing program, the field evaluation will be conducted by the District Offices and the General Office during their PACES survey. Moreover, to assist in the field evaluation, a report consisting of the location information, pavement conditions, crash history, roadway characteristics, and the initial safety index, as shown in Figure 5.3, will be generated for projects identified with safety concerns. After the field evaluation, GDOT's engineers will confirm the level of safety concern by assigning a final safety index to the project. The final safety index is categorized into four safety concern levels including no concern (safety index = 0), low concern (safety index = 0.25), median concern (safety index =

0.5), or high concern (safety index = 1). This final safety index will be used to reprioritize the resurfacing projects (see Section 5.4).

LOCATION INFORMATION

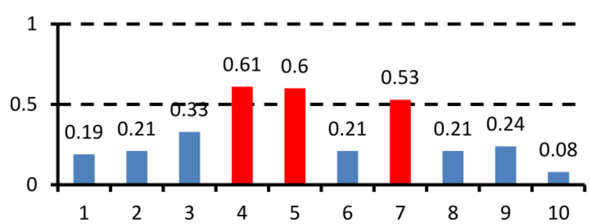
District:	6	**County:**	Cherokee	**Route:**	SR 20
Location:	MP 0.00 to MP 9.40 (begins at the Bartow County line and extending to Canton Road Spur (CR1870))				

Map:

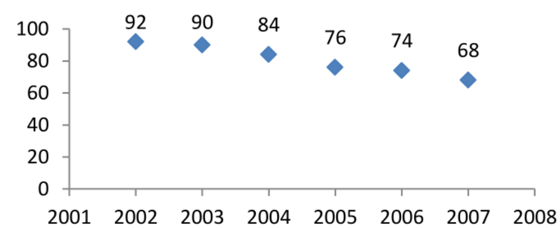


Video Log:

SEGMENT SAFETY INDEX



PROJECT PACES RATING HISTORY



PAVEMENT CONDITION DATA

Segment	1	2	3	4	5	6	7	8	9	10
Segment PACES Rating	78	60	63	60	67	68	66	74	74	72
Difference in Rating (Segmenet Rating - Project Rating)	-10	8	5	8	1	0	2	-6	-6	-4
Rut Depth (in.)	2/8	1/8	2/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8
Number of Patches and Potholes	1	5	2	4	5	3	1	1	3	4

CRASH DATA

Segment	1	2	3	4	5	6	7	8	9	10
3-Year Accident Rate (accident/mi/year)	2.333	1.667	3.000	11.667	5.333	1.333	5.667	5.667	3.333	2.333
3-Year Wet Surface Accident Percentage (%)	29%	20%	22%	51%	38%	0%	76%	29%	30%	0%
3-Year Fatality Rate (fatalities/mi/year)	0.000	0.000	0.000	1.000	1.000	0.000	0.667	0.000	0.000	0.000
3-Year Injury Rate (injuries/mi/year)	3.333	0.667	1.000	4.667	2.667	1.333	3.333	3.333	4.000	0.000
Number of 3-Year Road Defects	0	0	1	0	1	1	1	0	0	0
Roadway Characteristics (1-Straight, Curve&Level; 2-Cuver&Grade; 3-Curve&Hill)	1	1	2	2	2	2	2	1	1	1

FINAL SAFETY INDEX

Safety Concern:

- ◯ NO CONCERN
- ◯ LOW CONCERN
- ◯ MEDIAN CONCERN
- ◯ HIGH CONCERN

Comments:

Figure 5.3 Report to Support Field Safety Evaluation

(Image Sources: Google Maps)

SAFETY DATA (2007)

Total Crashes

Year	Crashes	Injuries	Fatalities
2004	37	8	0
2005	38	25	3
2006	52	25	1
2007	37	23	4

Manner of Collision

Manner of Collision	Crashes	%
Angle	5	13.5%
Head On	2	5.4%
Rear End	9	24.3%
Sideswipe - Same Direction	0	0.0%
Sideswipe - Opposite Direction	3	8.1%
Not a Collision w/Motor Vehicle	18	48.6%

Surface Condition

Surface Condition	Crashes	%
Dry	21	56.8%
Wet	16	43.2%
Snowy	0	0.0%
Icy	0	0.0%
Other	0	0.0%

Location At Area of Impact

Location At Area of Impact	Crashes	%
On Roadway	21	56.8%
On Shoulder	2	5.4%
Off Roadway	14	37.8%
Median	0	0.0%
Ramp	0	0.0%
Gore	0	0.0%

First Harmful Event

First Harmful Event	Crashes
Overturn	3
Ditch	4
Motor Vehicle In Motion	19
Deer	1
Other - Fixed Object	10
Total	37

Lighting Conditions

Lighting Conditions	Crashes	%
Daylight	24	64.9%
Dusk	0	0.0%
Dawn	1	2.7%
Dark - Lighted	0	0.0%
Dark - Not Lighted	12	32.4%

Figure 5.3 Report to Support Field Safety Evaluation (Cont'd)

5.3.2 Identification of Roadway Upgrade Needs

Figure 5.4 shows a two-stage approach proposed to identify the need for Category 2 safety improvements in order to upgrade roadways to meet enhanced safety standards (e.g., edge line rumble strips and guardrails). Again, the first stage is the in-house computerized search, and the second stage is the field evaluation. Resurfacing project candidates will be evaluated, along with crash data and roadway characteristics, and a field evaluation will be conducted if the criteria are met in the first stage.

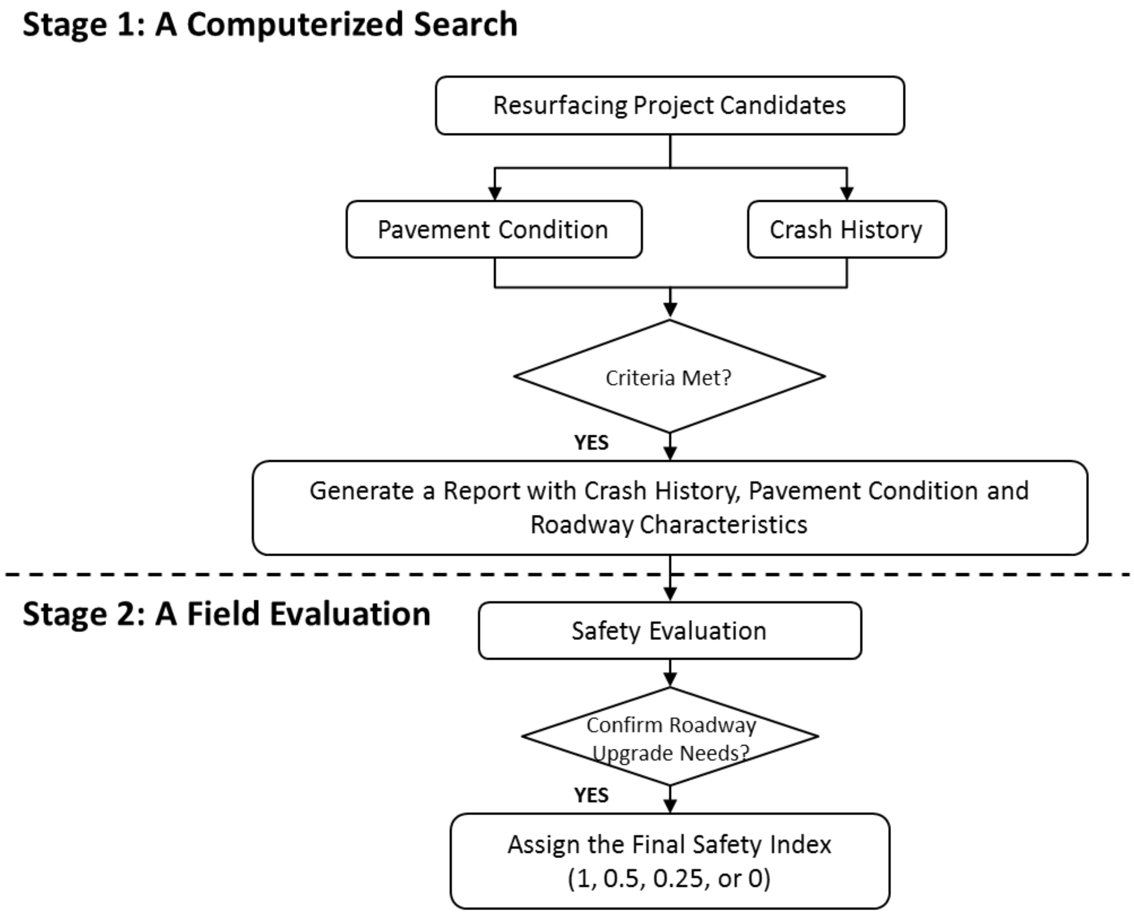


Figure 5.4 Two-Stage Roadway Upgrade Needs Identification

After discussion with the Office of Traffic Operations, certain roadway upgrade needs, such as edge line rumble strips, identified through the system-wide study can be incorporated into the resurfacing program. Table 5.2 shows the safety improvements that are included in Category 2 and the criteria for implementing/installing them. Again, the criteria may be refined by the Office of Traffic Operations in Phase 2 based on statistical analysis of historical crash data. Among those safety improvements listed in Table 5.2, edge line rumble strips installation is suggested as the first safety improvement to be incorporated into the resurfacing program because it is one of the top priority safety program initiatives identified by the Office of Traffic Operations to mitigate Georgia's run-off-the-road accidents.

Table 5.2 Category 2 Safety Improvements

Safety Improvement	Proposed Roadway Condition	Proposed Crash Criteria
Shoulder Rumble Strips	>= 4 ft. shoulder with adequate pavement structure	➢ 10 crash per year ➢ 50% single vehicle run off road
Centerline Rumble Strips	2-lane roadway >=11 ft. lane width >= 2 ft. paved outside shoulder	➢ 10 crash per year ➢ 40% head on and opposite direction sideswipe
Edge Line Rumble Strips	2-lane roadway >=11 ft. lane width < ft. paved outside shoulder	➢ 10 crash per year ➢ 50% single vehicle run off road
Cable Barrier Systems (3-cable system)	Limited access <=40 ft. unprotected median	➢ Crossover crash
Guardrail Delineation	All state-maintained roads	
Raised Pavement Marker	All state-maintained roads	
Sign		➢ Review manually

For the projects that meet the criteria in Table 5.2, a field evaluation will be conducted. This process is similar to the pavement-deficiency-induced safety concerns identification. Again, a report with crash history, pavement condition, and roadway characteristics will be provided to GDOT's engineers during the field evaluation. A final safety index (1, 0.5, 0.25, or 0) will also be assigned by GDOT's engineers for project reprioritization (see Section 5.4).

5.4 Project Reprioritization

In order to align with GDOT's current resurfacing prioritization method, which is based on the PACES rating, the final safety index is incorporated into the PACES rating to generate a modified PACES rating, as shown in Figure 5.5. The modified PACES rating that takes into account safety will be used for reprioritizing resurfacing projects. The design is to advance the deferred resurfacing projects and upcoming projects with safety concerns or roadway upgrade needs to minimize potential safety risks.

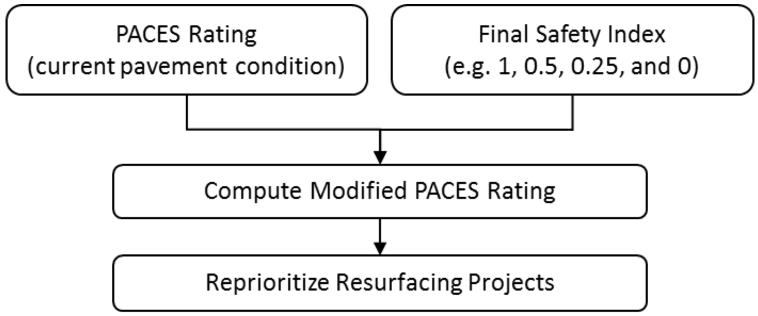


Figure 5.5 Project Reprioritization Method

Two alternatives for the modified PACES rating are proposed as follows:

Alternative A:

As shown in Equation 1, the modified PACES rating is computed by deducting a portion of the original PACES rating to address safety concerns. The deducted portion is defined using the final safety index and a weighting factor, a.

$$\text{Modified PACES Rating} = \text{PACES Rating} - a \times (\text{Safety Index} \times \text{PACES Rating}) \qquad (1)$$

where

a: a weighting factor to address safety concern in the PACES rating.

PACES Rating: a rating (0-100) represents the overall pavement condition.

Safety Index: the final safety index (i.e., 1, 0.5, 0.25, or 0).

The weighting factor a can be back-calculated and further adjusted by GDOT under the consideration of the current PACES rating and the expected rating, which will take safety into account. Currently, the weighting factor is set as 0.22 to bring a PACES rating of 90 down to 70 for the project with high safety concerns or urgent needs for roadway upgrade (i.e., with the final safety index equals to 1). In addition, the above equation is designed to give a lower PACES rating to reprioritize a project to a higher priority in the resurfacing list when the safety concern is high. Take a project with an original PACES rating of 80, for example; the modified PACES ratings with respect to the four final safety indices, i.e., 1, 0.5, 0.25, and 0, are 62, 71, 76, and 80, respectively.

Alternative B:

Similar to Alternative A, Equation 2 is proposed to compute the modified PACES rating. The modified PACES rating is computed using the original PACES rating divided by the safety index plus one. For example, for a high safety concern project (i.e., the final safety index is 1), the modified PACES rating will be only half of the original PACES rating based on this equation.

$$\text{Modified PACES Rating} = \text{PACES Rating} / (1+\text{Safety Index}) \tag{2}$$

where

PACES Rating: a rating (0-100) represents the overall pavement condition.

Safety Index: the final safety index (e.g., 1, 0.5, 0.25, or 0).

After the discussion with the Office of Maintenance, Alternative A was selected for implementation since the weighting factor, *a*, can be adjusted and determined by GDOT based on the back-calculation given the pre-specified condition. Also, the formulation of Alternative A can be easily extended to include other impact factors, such as traffic, population, economics, and environmental impacts.

5.5 A Safety-Incorporated Resurfacing Program for GDOT

An enhanced, safety-incorporated pavement resurfacing program is proposed to systematically integrate the aforementioned components into GDOT's existing fast-paced pavement resurfacing program. The new operation procedure is shown in Figure 5.6, and the modified steps (in gray color) are described below.

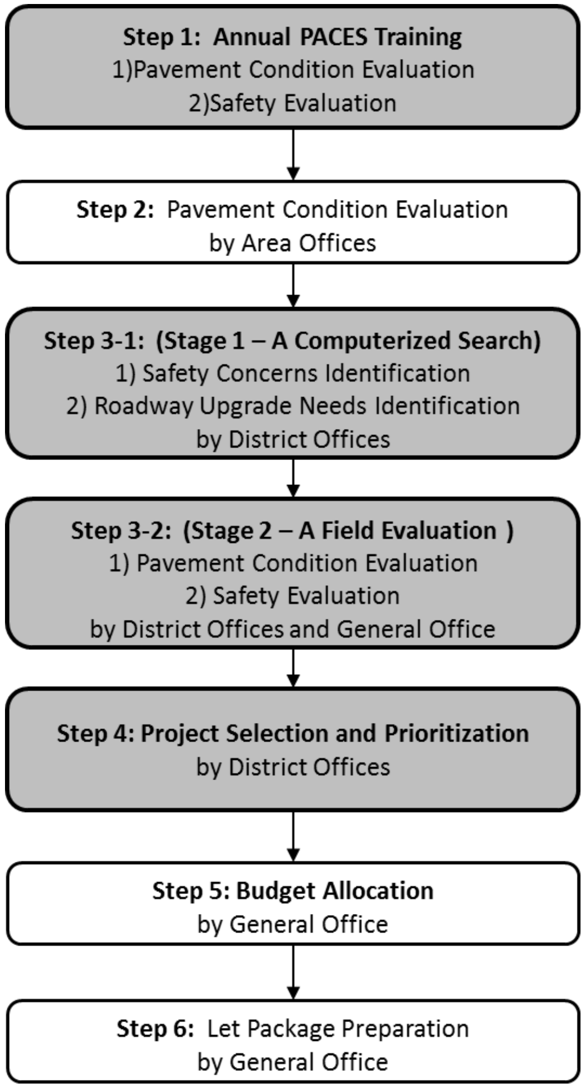


Figure 5.6 Safety-Incorporated Resurfacing Program for GDOT

Step 1: Annual Training

As described in Chapter 3, the Office of Maintenance conducts the PACES training for all participating engineers before the annual PACES survey. A roadway safety evaluation training is proposed to be included in the annual PACES training.

Step 3-1: Computerized Search by District Offices

The two-stage safety concerns and roadway upgrade needs identification approach is incorporated into the PACES survey conducted by the District Offices and the General Office.

The District Offices conduct in-office computerized search to identify potential pavement-deficiency-induced safety concerns and roadway upgrade need in deferred and upcoming (e.g., a rating of PACES rating <=80) resurfacing projects, and further determine the initial safety index to represent the safety concern level. A report covering the initial safety index, pavement condition, crash history, and roadway characteristics is generated for any project that meets the safety concerns or roadway upgrade needs criteria.

Step 3-2: Field Evaluation by District Offices and General Office

The projects identified as with safety concerns or roadway upgrade needs in Step 3-1are further evaluated in the field by the District Offices and the General Office. The field evaluation includes the pavement condition evaluation (i.e., PACES), as well as the proposed safety evaluation. The District Offices will categorize the safety concern into four levels (i.e., high, median, low, and no concern) and determine the final safety index (i.e., 1, 0.5, 0.25, and 0, respectively). The safety index is used as the basis for the project reprioritization in the next step. The safety data (e.g., safety index) collected during the field evaluation will be stored in the database along with the pavement condition data for reprioritizing projects and tracking safety concerns.

Step 4: Project Prioritization and Selection by District Offices

Instead of using the PACES rating solely based on pavement conditions, the District Offices will use the modified PACES rating to select and prioritize resurfacing projects. This modified PACES rating is computed using the safety index assigned by the District Offices in Step 3-2 to give a higher priority (e.g., lower modified PACES rating) to projects with safety concerns. Again, the District Offices can make final decisions on the treatment methods and the priority based on their experience and understanding of the project.

6 Case Study

This chapter presents a case study conducted using the actual data of a deferred resurfacing project to demonstrate the feasibility of the proposed program. This case study focuses on using the proposed program to identify the safety concerns and assessing the feasibility of the project reprioritization results. First, project information, such as the data used in this case study, is introduced. Second, the two-stage safety concerns identification process, including computerized search and field evaluation, is presented. Finally, the computation of the modified PACES rating and the discussion over possible reprioritization results are presented.

6.1 Project Description

A deferred resurfacing project located on State Route 20 from the Bartow County line to Canton Road Spur (i.e., Milepost 0 to 9.4) in Cherokee County, Georgia was selected for this case study. It was a 3-lane rural highway project. According to GDOT's current resurfacing project selection criterion, i.e., a project is recommended for resurfacing if its PACES rating is 70 or below, this project was qualified for a resurfacing treatment in 2007. However, it was not scheduled for resurfacing until 2010 due to the funding shortage.

The data necessary to support the case study includes historical pavement condition data from the GPAM database and historical crash data from the crash database. The GPAM database stores pavement condition data collected through annual PACES survey, including segment-level PACES rating project-level PACES rating, and detailed pavement distresses (e.g., type, severity level, extent, etc.). The crash database stores crash report information including time, date, weather conditions, pavement surface conditions, crash types, number of fatalities, number of injuries, driver information, etc. Four consecutive years (2005 to 2008) of pavement condition data in the GPAM database and associated crash data were used to demonstrate the ability of the proposed program to reprioritize projects with safety concerns, and move the project with safety concern to a higher priority for a timely treatment. Since the number of crashes may vary excessively from year to year, crash data was compiled on a 3-year basis to attenuate possible extreme cases. For example, the crash data compiled for year 2005 in fact covers the crash history data in 2003, 2004, and 2005. In other words, a total of 6 years (i.e., 2003 to 2008) of crash history data were used to support the analysis from 2005 to 2008.

6.2 Identification of Safety Concerns

According to the proposed program, project safety concerns are identified through a two-stage approach: the computerized search stage and the field evaluation stage. This section presents the detailed steps for identifying safety concerns using actual data.

6.2.1 Computerized Search

First, ten safety factors, including accident rate, fatality rate, injury rate, wet pavement accident percentage, number of road defects in accident reports, roadway characteristics, PACES segment rating, difference between project and segment rating, rut depth, and number of potholes/patches, are extracted from different databases for each segment in the project. There are a total of 10 segments in this 9.4-mile project. Table 6.1 presents the values of these safety factors and their corresponding weighted values determined based on the criteria in Table 5.1. For example, the PACES rating for Segment 1 in 2005 was 76 and the corresponding weighted value was 1, as shown in Table 6.1. For each segment, a safety index is computed as one hundredth of the sum of the ten weighted values, and the highest segment safety index within the project is assigned as the initial project safety index, as depicted in Table 6.2. For example, segment safety indexes in 2005 range from 0.06 (Segment 10) to 0.41 (Segment 4). Therefore, the initial project safety index is assigned to 0.41 (the highest value).

Table 6.1 Safety Factors and Weighted Values

2005

Segment	1	2	3	4	5	6	7	8	9	10
Segment PACES Rating	76 (1)*	80 (0)	74 (1)	73 (1)	77 (1)	77 (1)	75 (1)	82 (0)	85 (0)	84 (0)
Difference in Rating	0 (0)	-4 (0)	2 (0)	3 (0)	-1 (0)	-1 (0)	1 (0)	-6 (0)	-9 (0)	-8 (0)
Rut Depth	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)
Number of Patches and Potholes	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
3-Year Accident Rate	3.333 (4)	2.667 (4)	2 (4)	7.667 (8)	3.667 (4)	2.333 (4)	5.667 (6)	4.667 (6)	5 (6)	3.333 (4)
3-Year Wet Surface Percentage	30 (10)	25 (5)	50 (10)	26 (5)	55 (10)	29 (5)	41 (10)	7 (0)	40 (10)	0 (0)
3-Year Fatality Rate	0.333 (10)	0 (0)	0 (0)	0.333 (10)	0 (0)	0 (0)	0.667 (15)	0 (0)	0 (0)	0 (0)
3-Year Injury Rate	0.667 (2)	1 (5)	0.333 (2)	4.333 (8)	2.667 (8)	1.667 (5)	4.333 (8)	2.333 (8)	2.667 (8)	0.667 (2)
Number of 3-Year Road Defects	0 (0)	0 (0)	0 (0)	1 (8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Roadway Characteristics	1 (0)	1 (0)	2 (1)	2 (1)	2 (1)	2 (1)	3 (2)	2 (1)	1 (0)	1 (0)
Sum of Weighted Values	27	14	18	41	24	16	32	15	24	6

2006

Segment	1	2	3	4	5	6	7	8	9	10
Segment PACES Rating	77 (1)	74 (1)	74 (1)	70 (1)	78 (1)	76 (1)	71 (1)	80 (0)	83 (0)	81 (0)
Difference in Rating	-3 (0)	0 (0)	0 (0)	4 (0)	-4 (0)	-2 (0)	3 (0)	-6 (0)	-9 (0)	-7 (0)
Rut Depth	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)
Number of Patches and Potholes	0 (0)	0 (0)	2 (0)	2 (0)	0 (0)	0 (0)	0 (0)	1 (0)	1 (0)	1 (0)
3-Year Accident Rate	3 (4)	2 (4)	2 (4)	8.667 (10)	6 (8)	2 (4)	6 (8)	5.667 (6)	4 (6)	3 (4)
3-Year Wet Surface Percentage	44 (10)	33 (10)	33 (10)	35 (10)	39 (10)	17 (2)	83 (10)	24 (5)	25 (5)	0 (0)
3-Year Fatality Rate	0 (0)	0 (0)	0 (0)	0.333 (10)	0.333 (10)	0 (0)	0.667 (15)	0 (0)	0 (0)	0 (0)
3-Year Injury Rate	0.333 (2)	0.333 (2)	0 (0)	3.333 (8)	3 (8)	1.667 (5)	3.667 (8)	3 (8)	4 (8)	0 (0)
Number of 3-Year Road Defects	0 (0)	0 (0)	1 (8)	1 (8)	0 (0)	1 (8)	1 (8)	0 (0)	0 (0)	0 (0)
Roadway Characteristics	1 (0)	1 (0)	2 (1)	2 (1)	2 (1)	2 (1)	3 (2)	1 (0)	1 (0)	1 (0)
Sum of Weighted Values	17	17	24	48	38	21	52	19	19	4

2007

Segment	1	2	3	4	5	6	7	8	9	10
Segment PACES Rating	78 (2)	60 (5)	63 (5)	60 (5)	67 (5)	68 (5)	66 (5)	74 (2)	74 (2)	72 (2)
Difference in Rating	-10 (0)	8 (5)	5 (5)	8 (5)	1 (0)	0 (0)	2 (0)	-6 (0)	-6 (0)	-4 (0)
Rut Depth	2/8 (0)	1/8 (0)	2/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)
Number of Patches and Potholes	1 (0)	5 (2)	2 (0)	4 (2)	5 (2)	3 (0)	1 (0)	1 (0)	3 (0)	4 (2)
3-Year Accident Rate	2.333 (4)	1.667 (2)	3 (4)	11.667 (10)	5.333 (6)	1.333 (2)	5.667 (6)	5.667 (6)	3.333 (4)	2.333 (4)
3-Year Wet Surface Percentage	29 (5)	20 (5)	22 (5)	51 (10)	38 (10)	0 (0)	76 (10)	29 (5)	30 (10)	0 (0)
3-Year Fatality Rate	0 (0)	0 (0)	0 (0)	1 (20)	1 (20)	0 (0)	0.667 (15)	0 (0)	0 (0)	0 (0)
3-Year Injury Rate	3.333 (8)	0.667 (2)	1 (5)	4.667 (8)	2.667 (8)	1.333 (5)	3.333 (8)	3.333 (8)	4 (8)	0 (0)
Number of 3-Year Road Defects	0 (0)	0 (0)	1 (8)	0 (0)	1 (8)	1 (8)	1 (8)	0 (0)	0 (0)	0 (0)
Roadway Characteristics	1 (0)	1 (0)	2 (1)	2 (1)	3 (2)	2 (1)	2 (1)	1 (0)	1 (0)	1 (0)
Sum of Weighted Values	19	21	33	61	61	21	53	21	24	8

2008

Segment	1	2	3	4	5	6	7	8	9	10
Segment PACES Rating	68 (5)	60 (5)	60 (5)	60 (5)	63 (5)	68 (5)	63 (5)	71 (2)	71 (2)	72 (1)
Difference in Rating	-1 (0)	7 (5)	7 (5)	7 (5)	4 (0)	-1 (0)	4 (0)	-4 (0)	-4 (0)	-5 (0)
Rut Depth	2/8 (0)	1/8 (0)	2/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)	1/8 (0)
Number of Patches and Potholes	1 (0)	4 (2)	2 (0)	4 (2)	3 (0)	3 (0)	1 (0)	1 (0)	3 (0)	3 (0)
3-Year Accident Rate	2.333 (4)	1.667 (2)	4 (6)	18 (10)	8.333 (10)	1 (2)	5.667 (6)	4.333 (6)	2.333 (4)	2.333 (4)
3-Year Wet Surface Percentage	29 (5)	20 (5)	17 (2)	61 (10)	64 (10)	0 (0)	82 (10)	38 (10)	14 (2)	0 (0)
3-Year Fatality Rate	0 (0)	0 (0)	0 (0)	1 (20)	1 (20)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
3-Year Injury Rate	3 (8)	0.333 (2)	1.667 (5)	10.667 (8)	5.333 (8)	1.333 (5)	2 (8)	1.667 (5)	4 (8)	0.667 (2)
Number of 3-Year Road Defects	0 (0)	0 (0)	1 (8)	2 (15)	3 (15)	1 (8)	1 (8)	0 (0)	0 (0)	0 (0)
Roadway Characteristics	2 (1)	1 (0)	2 (1)	3 (2)	3 (2)	2 (1)	2 (1)	1 (0)	1 (0)	1 (0)
Sum of Weighted Values	23	21	32	77	70	21	38	23	16	7

* A (B): where A is the number/rate of the safety factor, B is the corresponding weighted value. For example, here 78 is the segment PACES rating and 2 is the assigned weighted value.

Table 6.2 Initial Safety Index Results

Segment	Segment Safety Index			
	2005	2006	2007	2008
1	0.27	0.17	0.19	0.23
2	0.14	0.17	0.21	0.21
3	0.18	0.24	0.33	0.32
4	0.41	0.48	0.61	0.77
5	0.24	0.38	0.61	0.70
6	0.16	0.21	0.21	0.21
7	0.32	0.52	0.53	0.38
8	0.15	0.19	0.21	0.23
9	0.24	0.19	0.24	0.16
10	0.06	0.04	0.08	0.07
Initial Project Safety Index	0.41	0.52	0.61	0.77

6.2.2 Field Evaluation

According to the proposed program in Chapter 5, the field evaluation is needed for a project with an initial safety index equal to or greater than 0.5. Based on the results shown in Table 6.2, a field evaluation is required for three years from 2006 to 2008. A report including the information from the computerized search (e.g., safety index and crash data summary for each segment) will be provided to GDOT's engineers to assist the field evaluation. A final safety index will be assigned to the project by GDOT's engineers after evaluating the field conditions. The final safety index indicates the level of safety concern of the project. Projects with higher safety concerns (i.e., higher safety index) should be given a higher priority for resurfacing than other projects. For this case study, however, since the actual field conditions of the past years cannot be observed and evaluated, all four possible values of the final safety index, i.e., 1, 0.5, 0.25, and 0, are considered and discussed in the following section.

6.3 Project Reprioritization

Based on the proposed program, a modified PACES rating is computed to reprioritize the projects with safety concerns. This section first presents the computation of the modified PACES ratings through the analysis period (2005 to 2008), followed by a discussion on the reprioritization results.

6.3.1 Modified PACES Rating

As proposed in Chapter 5, the modified PACES rating can be computed by deducting a portion of the original PACES rating to address safety concerns; the deducted portion is defined using the final safety index and a weighting factor, *a*, as shown in Equation 1 in Section 5.4.

The weighting factor *a*, which can be further adjusted by GDOT, as described previously in Chapter 5, is set as 0.22 in order to bring the PACES rating of a project with high safety concerns (i.e., safety index equals 1) from 90 to 70. The modified PACES ratings computed using different values of the final safety index of this project are shown in Table 6.3.

Table 6.3 Modified PACES Ratings

Year	2005	2006	2007	2008
Original Project PACES Rating (SI=0.00)	76	74	68	67
Modified PACES Rating (SI=0.25)	N/A	70	64	63
Modified PACES Rating (SI=0.50)	N/A	66	61	61
Modified PACES Rating (SI=1.00)	N/A	59	55	54

6.3.2 Discussion

Table 6.3 shows that the project could have been recommended for resurfacing in 2006 if there was any safety concern. The modified PACES rating of this project would be 70 (which warrants a resurfacing based on GDOT's criteria) if there was low safety concern (safety index =0.25). If the safety concern was high (i.e. safety index =1), the modified PACES rating would drop to 59, and, therefore, a higher priority for resurfacing would be given to this project.

The proposed program has demonstrated its capability to reprioritize projects so that the projects with higher safety concerns can have a higher priority for resurfacing. After discussion with GDOT, a safety index of 1 is most likely to be assigned to this project given the crash history and the wear-out on the pavement surface. This would result in a timely resurfacing in 2006, and the potential safety risks of this project could be reduced.

7 Design for the Proposed Safety-Incorporated Resurfacing Program

To facilitate the proposed safety-incorporated resurfacing program presented in Chapter 5, various tools/applications are needed to provide GDOT's engineers the abilities to conduct computerized search, generate reports, record the field evaluation, compute the modified PACES rating, and reprioritize projects. This chapter presents the design, including functions, use cases, and databases, for these tools/applications to support the development and implementation of the proposed program in Phase2.

7.1 Functional Design

The use cases necessary to support each step in the proposed safety-incorporated resurfacing program are presented in Figure 7.1. The five use cases are to report user-specified safety concerns, identify safety concerns and roadway upgrade needs, generate a report summarizing the pavement conditions and crash history, record the field evaluation, and reprioritize resurfacing projects based on both pavement conditions and safety concerns. The process and data flow between different offices are depicted in Figure 7.2, and the use case diagram is presented in Figure 7.3. The use cases are discussed in the subsequent section.

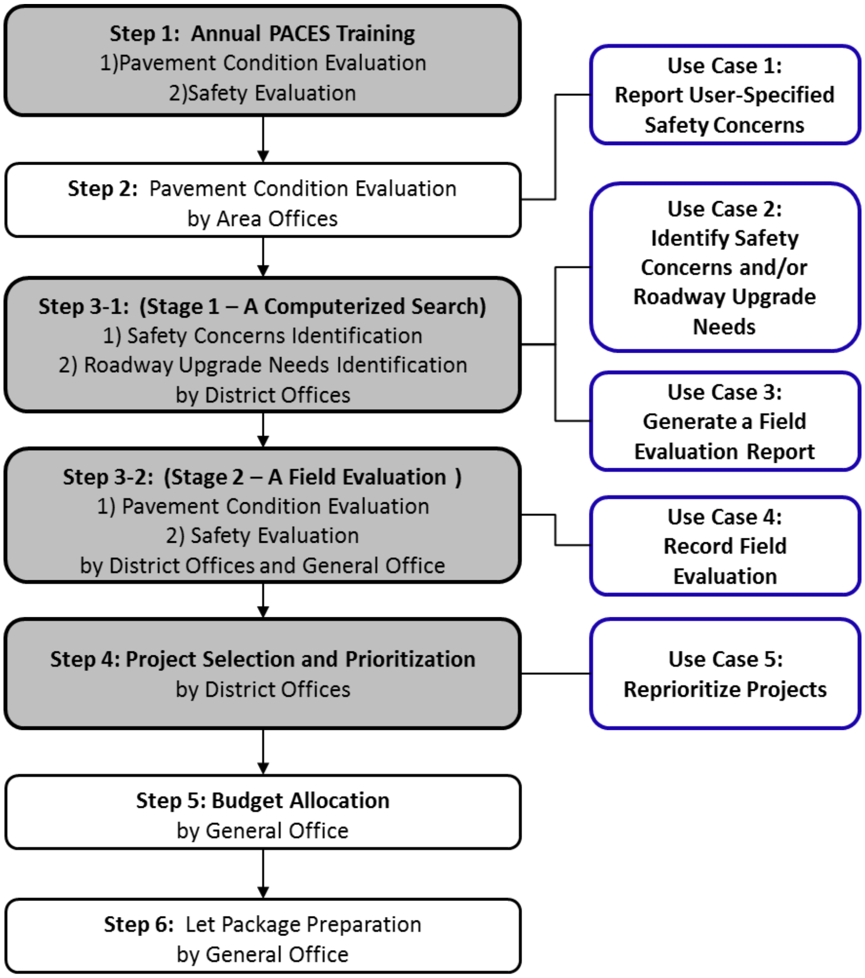


Figure 7.1 Use Cases for the Proposed Procedure

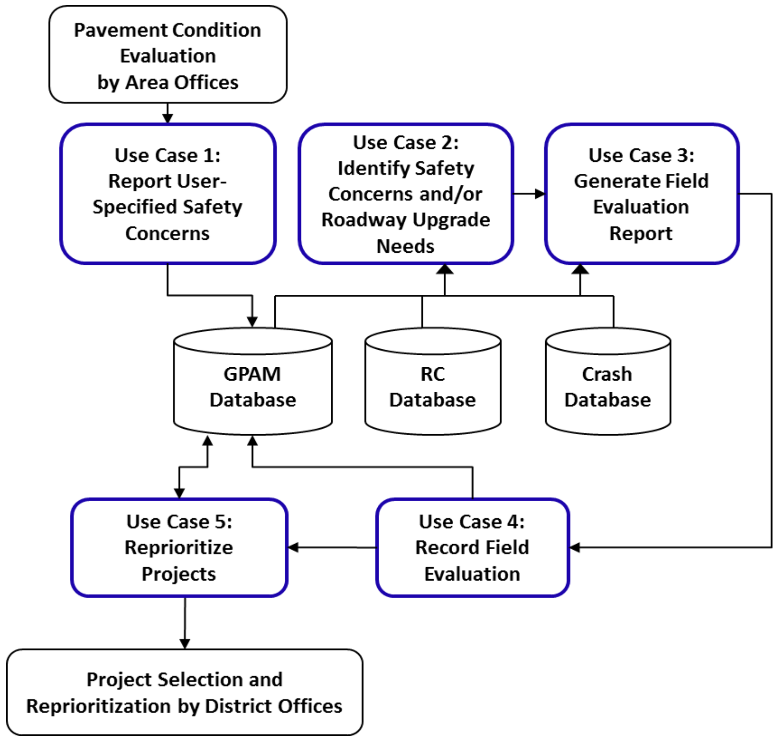


Figure 7.2 Process and Data Flow of the Proposed Safety-Incorporated Resurfacing Program

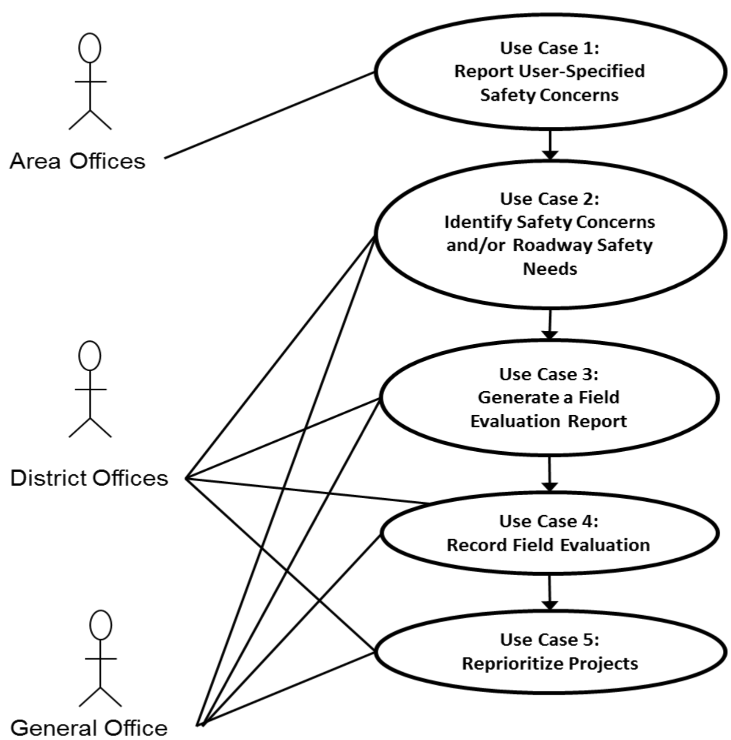


Figure 7.3 Use Case Diagram

7.2 Use Cases

This section presents the design for each of the use cases identified in the previous section in order to support the development and implementation of the proposed safety-incorporated safety program.

- *Report User-Specified Safety Concerns*

A function to allow the Area Offices to report the projects with safety concerns that are reported by local governments, city and county engineers, local agencies, etc., is proposed. This function will reside in the COPACES module in the GPAM; the use case is shown in Table 7.1.

Table 7.1 Use Case 1 – Report User-specified Safety Concerns

Use Case Element	Description
Use Case Number	1
Name	Report User-specified Safety Concerns
Description	This use case deals with entering the user-specific safety concerns that were reported by local engineers, emergency agencies, etc.
Primary Actor	Area Offices
Precondition	Area Offices complete the PACES survey.
Trigger	Transmittals requesting work on entering the data collected during the PACES survey received from Area Offices.
Basic Flow	1) Area Offices accept the report for safety concerns. 2) Query pavement condition evaluation data for a specific location based on county, route type, route number, route suffix, and milepost. 3) Add the safety concerns to these projects if no concern is identified by the program. 4) Assign a safety impact factor to the projects.
Input Sources	Pavement condition data
Output Sources	Modify database to store user-specified safety concerns.

- *Identify Safety Concerns and Roadway Upgrade Needs*

A function is needed to identify the projects with safety concerns and/or roadway upgrade needs. A computerized search is conducted based on integrated data, including the history and current pavement condition data, roadway characteristics data, and crash history to identify locations with potential safety concerns or roadway upgrade needs. This function will reside in the COPACES module in the GPAM, and is only accessible to the District Offices and the General Office. The use case, including the description, basic flow, input, and output, is shown in Table 7.2.

Table 7.2 Use Case 2 – Identify Safety Concerns and Roadway Upgrade Needs

Use Case Element	Description
Use Case Number	2
Name	Identify Safety Concerns and Roadway Upgrade Needs
Description	This use case deals with identification of safety concerns and/or roadway upgrade needs using pavement condition data, road characteristic data, and crash data
Primary Actor	District Offices and General Offices
Precondition	Area Offices submit the PACES survey to the GPAM
Trigger	Transmittals requesting work on downloading the PACES survey by the Area Offices received from District Offices or General Office.
Basic Flow	1) Query current year pavement condition data, crash history data, and roadway characteristics data for the locations with potential safety concerns and roadway upgrade needs based on the criteria discussed in Chapter 5. 2) A safety index will be computed based on the pre-defined rules to quantitatively represent the safety concern at the locations. 3) District Offices and General Office review the projects and add notes for known safety concerns.
Input Sources	Pavement condition data, road characteristic data, and crash data
Output Sources	Modify database to store the results of computerized search and the safety index.

- *Generate a Field Evaluation Report*

A function will be developed to generate a report for each project with safety concerns and/or roadway upgrade needs that requires a field evaluation by District and General Offices. This function will be used by the District Offices to generate the report before conducting a field survey. The function will reside in the COPACES module in the GPAM, and is only accessible to the District Offices.

Table 7.3 Use Case 3 – Generate a Field Evaluation Report

Use Case Element	Description
Use Case Number	3
Name	Generate a Field Evaluation Report
Description	This use case deals with generating a project for each project identified with safety concerns and/or roadway upgrade needs that require a field evaluation. The information on the report includes pavement condition evaluation data, road characteristic data, and crash data.
Primary Actor	District Offices and General Offices
Precondition	District Offices conducted the computerized search for the projects with safety concerns and/or roadway upgrade needs
Trigger	Transmittals requesting work on the PACES survey received from District Offices or General Office
Basic Flow	1) Query project(s) by location, including county, route no, route suffix, and milepoint. 2) For each project, query pavement condition evaluation data, road characteristic data, and crash data based on RCLINK and milepoint. 3) Generate a report using the template designed with the Office of Maintenance and Office of Traffic Operations.
Input Sources	Pavement condition data, road characteristic data, and crash data
Output Sources	An Excel report

- *Record Field Evaluation*

A function is needed to allow the District Offices and General Offices to record the results of the field evaluation, including safety improvements to be installed and the assigned final safety index. The function will reside in the COPACES module in the GPAM, and is only accessible to the District Offices.

Table 7.4 Use Case 4 – Record Field Evaluation

Use Case Element	Description
Use Case Number	4
Name	Record Field Evaluation
Description	This use case deals with recording the field evaluation, including the assigned final safety index and the safety improvements to be incorporated into a specific project. The information on the report includes pavement condition evaluation data, road characteristic data, and crash data.
Primary Actor	District Offices and General Office
Precondition	District Offices and General Office conducted field evaluation and entered the PACES survey.
Trigger	Transmittals requesting work on entering the PACES survey received from District Offices and General Office.
Basic Flow	1) Query pavement condition evaluation data, road characteristic data, and crash data to generate a report for each project. 2) Record the result of field evaluation, including final safety index and the confirmation of the safety improvements to be included in the resurfacing project. 3) Compute the modified PACES rating using the final safety index. 4) The user is allowed to edit, delete, and save the field evaluation result.
Input Sources	Pavement condition data
Output Sources	Modify database to store the information gathered during the field evaluation.

- *Reprioritize Projects*

A function is needed to reprioritize the resurfacing projects based on the modified PACES rating in order to take into account both pavement conditions and safety concerns. This function will reside in the District Office Project Selection (DPS) and the Generate Office Project Selection (GOPS) module in the GPAM.

Table 7.5 Use Case 5 – Reprioritize Projects

Use Case Element	Description
Use Case Number	5
Name	Reprioritize Projects
Description	This use case deals with reprioritizing resurfacing projects to incorporate the safety concerns.
Primary Actor	District Offices and General Office
Precondition	District Offices complete recording the field evaluation, including the safety index.
Trigger	Transmittals requesting work on reprioritizing projects received from District Offices or General Office.
Basic Flow	1) Compute the modified PACES rating based on the method proposed in Chapter 5. 2) Users specify the prioritization criteria. 3) Reprioritize the resurfacing projects based on user-specified criteria.
Input Sources	Pavement condition data
Output Sources	Modify database to store the priority for each project.

7.3 Databases

This chapter presents the identification of data integration required to support the necessary analyses, including the identification of the projects with pavement-deficiency-induced safety concerns and/or roadway upgrade needs, a recommendation for certain types of safety improvements, and the computation of the modified PACES rating. Some data items that might contribute to a roadway crash are the following:

- **Roadway Characteristics**
  - Horizontal alignment, i.e., curvature
  - Slope and gradient
  - Pavement type and width
  - Shoulder type and width
- **Pavement Conditions**
  - Pavement cracking
  - Pavement roughness

    - Pavement skid resistance
- **Traffic Management**
    - Traffic counts
    - Traffic signs
    - Pavement markings
    - Signalization
- **Environments**
    - Sight distance (stopping sight distance, intersection sight distance, etc.)
    - Artificial objects (pole, tree, guardrail, etc.)
    - Weather

The data listed above are collected and managed by different offices, including road inventory data in the RC database maintained by the Office of Transportation Data, pavement condition data in the GPAM database maintained by the Office of Maintenance, and crash data in the crash database maintained by the Office of Traffic Operations. A location referencing system is first defined to integrate the data across different databases, and the tables to be integrated are identified.

- *Linear Referencing System*

GDOT uses a linear referencing system consisting of a unique RCLINK and milepoint. Each section of roadway is associated with a RCLINK, which is a ten-digit code comprised of county code, route type, route number, and route suffix. Both point and linear feature can be represented using the RCLINK and milepoint. This linear referencing system will be used for integrating the data from different sources.

- *GPAM Database*

The GPAM database contains the pavement condition evaluation data, including PACES rating, rutting, load cracking, etc. Each record in the GPAM database is location referenced using the RCLINK and milepoint. The proposed database includes four tables in the GPAM database, as shown in Table 7.6, that are essential for determining and predicting pavement conditions. The location referencing information is stored in tblProjectLocatInfo (including county code, route type, route number, route suffix, and milepoint from and to). The four tables are linked through Tripdate and Routeno.

Table 7.6 GPAM Database

tblProjectLocatInfo
Status
TripDate
RouteNo
RouteSuffix
RouteType
ProjectRating
Rater
District
Office
CountyNo1
MilePostFrom1
MilePostTo1
CountyNo2
MilePostFrom2
MilePostTo2
CountyNo3
MilePostFrom3
MilePostTo3
AADT
STAA
PavementWidthMin
PavementWidthMax
PavementWidthTyp
ShoulderWidthMin
ShoulderWidthMax
ShoulderWidthTyp
UnpavedShoulderWidth
DividedHighway
Direction
NoBridge
BridgeWidth
SurfaceType
CGMilling
CGLength
ProjectRemark
ProjectLimit
FinalTreatment
AllTreatment
TreatmentVersion
Cost
NoofLane
TreatYear
TreatMethod
PercentTruck
total_len
Safety Impact Factor
Safety Countermeasure1
Safety Countermeasure2
Safety Cost
Safety Note

tblProjectSurveyInfo
TripDate
RouteNo
Rut_Avg
Load_Sev1_Avg
Load_Sev2_Avg
Load_Sev3_Avg
Load_Sev4_Avg
Block_Sev
Block_Avg
Reflect_Sev
Reflect_Avg
Ravel_Sev
Ravel_Avg
Edge_Sev
Edge_Avg
Bleed_Sev
Bleed_Avg
Corrug_Sev
Corrug_Avg
Loss_Sev
Loss_Avg
Slope_Avg
Patch_Avg
Rut_Deduct
Load_Sev1_Deduct
Load_Sev2_Deduct
Load_Sev3_Deduct
Load_Sev4_Deduct
Block_Deduct
Reflect_Deduct
Ravel_Deduct
Edge_Deduct
Bleed_Deduct
Corrug_Deduct
Loss_Deduct
Slope_Deduct
Patch_Deduct

tblSegmentSurveyInfo
TripDate
RouteNo
CountyNo
SegmentFrom
SegmentTo
Rut_Out_WP
Rut_In_WP
Load_Lev1
Load_Lev2
Load_Lev3
Load_Lev4
Block_Pct
Block_Lev
Reflect_No
Reflect_Len
Reflect_Lev
Ravel_Pct
Ravel_Lev
Edge_Pct
Edge_Lev
Bleed_Pct
Bleed_Lev
Corrug_Pct
Corrug_Lev
Loss_Pave_Pct
Loss_Pave_Lev
Cross_Slope_Left
Cross_Slope_Right
Patch_pothole

tblSegmentLocatInfo
TripDate
RouteNo
CountyNo
SegmentFrom
SegmentTo
SampleLocation
SegmentRating
LaneDirect
LaneNo
ProjectLimit
CrackWidth
CrackSealed
SegmentRemark
CountyRecord

- *Road Characteristics (RC) Database*

Maintained and updated by the Office of Transportation Data, GDOT's RC database contains rich information regarding to the roadway characteristics and condition (GDOT, 2009). More than 50 features, such as functional classes, pavement widths, speed limits, signalization information, etc., are stored in the database, and each record is location-referenced through RCLINK and milepoint (BEG_MEASURE and END_MEASURE), which represent a specific roadway segment. The RC database, as show in Table 7.7, is necessary for the implementation of the proposed program and is included in the proposed database.

.

Table 7.7 RC Database

Field Name	Abbreviated Field Name	Directional Attribute
COUNTY	COUNTY	NO
ROUTE_TYPE	ROUTE_TYPE	NO
ROUTE_NUM	ROUTE_NUM	NO
BEG_MEASURE	BEG_MEASURE	NO
END_MEASURE	END_MEASURE	NO
SECTION_LENGTH	LENGTH	NO
DESCRIPTION	DESCRIPTION	NO
DISTRICT	DISTRICT	NO
MAINT_AREA	MAINT_AREA	NO
POPULATION	POPULATION	NO
INVENTORY_DATE	INV_DATE	NO
DESIGNATED_WAY	DESIG_WAY	NO
TRUCK_ROUTE	TRK_ROUTE	NO
TRAVEL_WAY	TRVEL_WAY	NO
RURAL_URAN	RURL_URAN	NO
SPEED_LIMIT	SEEPD_LMT	NO
FAS_NUM	FAS_NUM	NO
TRUCK_ROUTE_ID	TRK_RTE_ID	NO
CONGRESS_DIST	CONG_DIST	NO
STATE_ROUTE_SEQ	SR_SEQ	NO
ACCESS_CONTROL	ACCES_CTRL	NO
OPERATION	OPERATION	NO
TOTAL_LANES	TOTAL_LANES	NO
SPECIAL_CLASS	SPEC_CLASS	NO
DIV_HWY_SHLDR_WIDTH_LFT	DHWSDWDLF	YES (Opposite Inventory Dir)
DIV_HWY_SHLDR_TYPE_LFT	DHWSDTPLF	YES (Opposite Inventory Dir)
DIV_HWY_SURF_WIDTH	DHWSUFWD	YES (Opposite Inventory Dir)
DIV_HWY_SURF_TYPE	DHWSUFTP	YES (Opposite Inventory Dir)
DIV_HWY_SHLDR_WIDTH_RT	DHWSDWDRT	YES (Opposite Inventory Dir)
DIV_HWY_SHLDR_TYPE_RT	DHWSDTPRT	YES (Opposite Inventory Dir)

Field Name	Abbreviated Field Name	Directional Attribute
DIV_HWY_MEDIAN_WIDTH	DHWMDWD	NO
DIV_HWY_MEDIAN_TYPE	DHWMDTP	NO
DIV_HWY_BARRIER_TYPE	DHWBARTP	NO
UDIV_HWY_SHLDR_WIDTH_LFT	UDHWSDWDLF	YES (Inventory Dir)
UDIV_HWY_SHLDR_TYPE_LFT	UDHWSDTPLF	YES (Inventory Dir)
UDIV_HWY_SURFACE_WIDTH	UDHWSUFWD	YES (Inventory Dir)
UDIV_HWY_SURFACE_TYPE	UDHWSUFTP	YES (Inventory Dir)
UDIV_HWY_SHLDR_WIDTH_RT	UDHWSDWDRT	YES (Inventory Dir)
UDIV_HWY_SHLDR_TYPE_RT	UDHWSDTPRT	YES (Inventory Dir)
AUX_LANE_WIDTH_LFT	AUXLN_WDLF	NO (Inventory Dir Only)
AUX_LANE_TYPE_LFT	AUXLN_TPLF	NO (Inventory Dir Only)
AUX_LANE_WIDTH_RT	AUXLN_WDRT	NO (Inventory Dir Only)
AUX_LANE_TYPE_RT	AUXLN_TPRT	NO (Inventory Dir Only)
MAINT_YEAR	MAINT_YEAR	NO
MAINT_TYPE	MAINT_TYPE	NO
IMPROVE_YEAR	IMPRV_YEAR	NO
FUNC_CLASS	FUNC_CLASS	NO
TRAFFIC_COUNT_TYPE	COUNT_TP	NO
TRAFFIC_COUNT_YEAR	COUNT_YEAR	NO
RIGHT_OF_WAY	ROW	NO
RW_TYPE	RW_TYPE	NO
TC_NUMBER	TC_NUMBER	NO
MAINTENANCE_SUR_DES	MANTSURDES	NO
SIDEWALK_LEFT	SIDEWALKLF	NO (Inventory Dir Only)
SIDEWALK_RIGHT	SIDEWALKRT	NO (Inventory Dir Only)
IMPROVE_TYPE	IMPRV_TYPE	NO
SIGNAL	SIGNAL	NO
AADT_OLD	AADT_OLD	NO
HPMS_ID	HPMS_ID	NO
PACES_RATING	PACE_RATIN	NO
AADT	AADT	NO
INTERSECT_ROAD1	INTSEC_RD1	NO
INTERSECT_ROAD2	INTSEC_RD2	NO
S_FUNCLASS_ID	S_FCLAS_ID	NO
DUAL_MAINT_RATING	DMNT_RATIN	NO
ROAD_WIDTH	ROAD_WIDTH	NO
DIVIDED	DIVIDED	NO
OPEN_TO_TRAFFIC	OPEN_TO_TRAFFIC	NO
CITY_CODE	CITY_CODE	NO
T_LANES_LEFT	T_LANE_LF	YES (Opposite Inventory Dir)
T_LANES_RIGHT	T_LANE_RT	YES (Inventory Dir)
LAND_DOMAIN	LAND_DOMAIN	NO
RCLINK	RCLINK	

- *Crash Database*

A standard police report for any vehicle crash on a public road in which there is an injury or $500 or more in property damage, is recorded by law enforcement agencies and is submitted to GDOT. The information on the report, including accident (e.g., citation issued and manner of collision), vehicle (e.g., direction of travel and vehicle maneuver), driver (e.g., age and alcohol test), passenger, as well as location, is coded and stored in the crash database. Again, the location is recorded based on the mile log location referencing system developed in the RC. Table 7.8 shows the accident and location tables that are essential for identifying the safety concerns; these tables will be included in the proposed database. The two tables are linked by an accident identifier, and the location referencing fields are LOC_RCLINK_IDENTIFIER and LOC_ACC_MILELOG in the location table.

Table 7.8 Crash Database

Accident_tbl

ACC_ID	DOT_UNIT_OF_MEAS
ACC_ACCNO	DOT_DIRECTION
ACC_NCICNO	DOT_OF_MARKER
ACC_JULDT	DOT_OF_MARK_DESC
ACC_CNTY_TYPE	DOT_NEXT_REF
ACC_ATIME	DOT_NEXT_REF_DESC
ACC_TNV	DOT_TRUE_INTERSEC
ACC_TNI	DOT_ROAD_OF_OCCUR
ACC_TNF	DOT_INTERSECT_WITH
ACC_ICO_TYPE	PDF_LINK
ACC_EMSN	RECORD_TYPE
ACC_EMSA	IS_XML_FINAL
ACC_HOSA	ACC_MICRO
ACC_INVS	XMLF_OFFICE_ARRIVED
ACC_CIT	XMLF_PHOTOS_TAKEN
ACC_HE1_TYPE	XMLF_PHOTOS_TAKEN_BY
ACC_WEAT_TYPE	XMLF_REPORT_BY
ACC_SURF_TYPE	XMLF_REPORT_DEPT
ACC_LITE_TYPE	XMLF_DATE_RECORDED
ACC_MNRC_TYPE	XMLF_CHECKED_BY
ACC_LOI_TYPE	XMLF_DATE_CHECKED
ACC_RCOMP_TYPE	XMLF_ACC_INVESTIG_SITE
ACC_RDD_TYPE	XMLF_AIS_SITE
ACC_RCHAR_TYPE	ACC_EPROCESSFLAG
ACC_DAYOFWEEK_TYPE	
DMVS_LAST_UPDATE	
DMVSDOT_LAST_UPDATE	
ACC_NO_OF_OCCUP	
ACC_TRAFFIC_FLOW	
ACC_OTHER_DAMAGE	
ACC_HIT_N_RUN	
ACC_WORK_ZONE	
ACC_SUPP_MICRO	
ACC_SUPPMENTAL	
ACC_LAST_UPDATE	
ACC_NUM_SUFFIX	
ACC_CORRECTED	
DOT_RD_OCCUR_DESC	
DOT_INTR_W_DESC	
DOT_DISTANCE_FROM	

Location_tbl

LOC_ACC_ID
LOC_ACC_JULDT
LOC_RCLINK_IDENTIFIER
LOC_CITY_IDENTIFIER
LOC_COUNTY_IDENTIFIER
LOC_ROUTE_TYPE
LOC_ROUTE_IDENTIFIER
LOC_ROUTE_SUFFIX
LOC_ACC_MILELOG
LOC_ACC_MILELOGCUM
LOC_INTERROUTE_TYPE
LOC_INTERROUTE_IDENTIFIER
LOC_INTERROUTE_SUFFIX
LOC_ACCESSCONTROL_TYPE
LOC_AADT_COUNT
LOC_AUXLANELEFT_TYPE
LOC_AUXLANERIGHT_TYPE
LOC_AUXLANELEFT_WIDTH
LOC_AUXLANERIGHT_WIDTH
LOC_DIVHWYBARRIER_TYPE
LOC_DIVHWYMEDIAN_TYPE
LOC_FEDELIG_TYPE
LOC_FUNCTIONALCLASS_TYPE
LOC_RURALURBAN_TYPE
LOC_SIGNAL_TYPE
LOC_SPEEDLIMIT_NUMBER
LOC_LANESLEFT_COUNT
LOC_LANESRIGHT_COUNT
LOC_LOCATE_DATE
LOC_LOCATOR_IDENTIFIER
LOC_X
LOC_Y

8 Conclusions and Recommendations

To improve highway safety for meeting its goal of reducing highway crash fatalities by 4% each year (GOHS, 2010), GDOT is actively seeking opportunities to incorporate safety improvements into its current pavement preservation program. This project is proposed, with a focus on GDOT's resurfacing program, one of the most commonly used pavement preservation methods. After a review of GDOT's and other states' current practices, and intensive discussions with the Office of Maintenance and the Office of Traffic Operations, an enhanced, safety-incorporated resurfacing program that can systematically integrate safety improvements into GDOT's existing resurfacing program has been proposed. The proposed safety-incorporated resurfacing program will enable GDOT to 1) identify and reprioritize resurfacing projects that have a high potential of pavement-deficiency-induced safety concerns, 2) systematically identify proper safety improvements for a resurfacing project to comply with enhanced safety standards, and 3) optimize limited resources and reduce traffic interruption. The following summarizes the results of this study:

1) A safety improvements categorization strategy is proposed to make the integration of safety into the pavement resurfacing program practically feasible. The proposed strategy divides safety improvements into three categories based on the integration efforts in terms of duration, funding, and office coordination. The three categories are 1) resurfacing that addresses pavement-deficiency-induced safety concerns; 2) safety improvements require no environmental studies that upgrade the roadway system to meet enhanced safety standards; and 3) safety improvements that require environmental studies. The first two categories are proposed to be incorporated into the resurfacing program and the third category is proposed to be submitted to the Office of Roadway Design for further evaluation and design.
2) A two-stage approach is proposed to identify pavement-deficiency-induced safety concerns and roadway upgrade needs for meeting enhanced safety standards. The two stages are 1) a computerized search based on the 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 and criteria are proposed to support the computerized search after discussions with the Office of Maintenance and the Office of Traffic Operations. Refinement of these criteria and thresholds will be carried out in Phase 2 based on the statistical analyses on historical crash data performed by the Office of Traffic Operations.

3) A project reprioritization method based on the modified PACES rating that takes into account both pavement conditions and safety concerns is proposed; the method will be able to reprioritize deferred resurfacing projects with safety concerns to minimize safety risks.
4) A safety-incorporated resurfacing program based on the aforementioned strategy, approach, and method is proposed for GDOT to incorporate safety improvements into its existing fast-paced pavement resurfacing program.
5) A case study, using the actual data of a 9.4-mile resurfacing project in Cherokee County, has demonstrated the feasibility of the proposed program to identify and reprioritize deferred resurfacing projects with safety concerns, thus minimize safety risks.
6) The design for the functions and the databases to support the safety-incorporated resurfacing program is also proposed in this study. The data needed from different offices, such as the Office of Maintenance (pavement condition data), the Office of Traffic Operations (crash data), and the Office of Transportation Data (roadway characteristics data) has been identified, along with a linear referencing system for spatially integrating these data.

The implementation of the proposed safety-incorporated resurfacing program will be carried out in another project (Phase 2). Recommendations for future research of this study are as follows:

1) GDOT's high priority statewide safety improvements (e.g., rumble strips) can be used for initial implementation to align research focuses well with GDOT's needs and to simplify the potential challenges. A broader spectrum of safety improvements can be incorporated after the successful implementation.
2) Training material, including roadway safety assessment and enhancement considerations,

can be developed and incorporated into the annual pavement condition evaluation training in Phase 2 of this research to promote roadway safety consensus.

3) It is recommended that GDOT adopt the proposed program as a cost-effective means to upgrade statewide roadways through the resurfacing program operated by the Office of Maintenance. Additional funding may be allocated through different sources to strategically upgrade Georgia's roadway system to meet enhanced safety standards.
4) Besides incorporating safety factors, a comprehensive, risk-based resurfacing project prioritization can be developed in the future by incorporating other risk factors, including traffic, population, and economics.
5) Roadway characteristics data and pavement surface texture data are important information to support the analyses on identifying roadways with safety concerns. However, most transportation agencies lack a cost-effective means to collect such data. Developing an intelligent and integrated system to conduct a cost-effective, comprehensive roadway assessment at focused locations is recommended; the system should automatically extract roadway characteristics (e.g., curve, cross slope, superelevation, sight distance measurement, and obstruction identification), as well as pavement surface texture (e.g., macrotexture and friction) using advanced sensing technologies, such as GPS/GIS, computer vision, and 3D laser/LiDAR technologies.

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Appendix I. NYSDOT's Resurfacing Safety Assessment Form

Table A-1 Resurfacing Safety Assessment Form (Page 1 of 2)

PIN =		Date =	
Safety Assessment Team Design = Traffic = Maintenance =			
✔	**Element**	**Guidance**	**Comments**
The Following Elements Apply to Single <u>and</u> Multicourse Resurfacing Projects (1R, 2R, and 3R):			
	Signing	• Signs should be installed as needed in accordance with the MUTCD. Review for condition (retroreflectivity), location, post type (breakaway or rigid), and appropriateness (need). • Immediately notify the Resident Engineer of any missing regulatory or warning signs.	
	Pavement Markings	Pavement markings should be installed in accordance with the MUTCD. The adequacy of existing passing zones should be evaluated. Current EI's and specifications must be followed.	
	Delineation	Delineation should be installed per the MUTCD	
	Sight Distance	Trim, remove, or replace vegetation to improve substandard intersection sight distance, and horizontal and vertical stopping sight distance. Guidance: • Intersection Sight Distance - HDM §5.9.5.1 • Passing Sight Distance - HDM §5.7.2.2 • Horizontal & Sag Vertical SSD - HDM Chapter 2 and HDM §5.7.2.1 and HDM §5.7.2.4	
	Fixed Objects	For 1R projects: Address obvious objects that are within the prevailing clear area and within the ROW based on engineering judgment from a field visit (e.g., tree removal on the outside of a curve or installation of traversable driveway culvert end sections). For 2R/3R projects: Reestablish the clear zone and remove, relocate, modify to make crash worthy, shield by guide rail/crash cushion, or delineate any fixed objects. For guidance on identifying fixed objects, refer to HDM §10.3.1.2 B.	
	Guide Rail	The following should be used to evaluate the need for guide rail and other roadside work. • HDM §10.2.2.1 - point of need • HDM Table 10-7 - acceptable guide rail height • HDM §10.3.1.2 B - guidance on determining severely deteriorated guide rail and non-functional guide rail • HDM §10.2.2.3 and Table 10-3 - barrier deflection distance • HDM §10.2.2 - design of new guide rail • Current EIs and EBs.	
	Bridge Rail Transitions	The Regional Structures Group, Regional Design Group, Main Office Structures, and Design Quality Assurance Bureau should be contacted, as needed, to help identify substandard connections to bridge rail and for the recommended treatment.	
	Rail Road Crossing	Contact Regional Rail Coordinator. Contact Office of Design if replacing crossing surface as required per HDM Ch 23.	
	Rumble Strips	On rural, high speed facilities (80 km/h or greater) consider shoulder rumble strips in accordance with HDM §3.2.5.4. Centerline rumble strips should be considered for similar facilities and where head-on and sideswipe rates are above average.	

Table A-1 Resurfacing Safety Assessment Form (Page 2 of 2)

✔	Element	Guidance	Comments
	Shoulder Resurfacing	Unpaved, stabilized shoulders should be paved in order to reinforce the edge of the traveled way, accommodate bicyclists, and increase safety. A 1:10 pavement wedge maybe used to transition between the travel way paving and a paved shoulder that will not be resurfaced on nonfreeways.	
	Edge Drop-Offs	Edge drop-offs are not permitted between the traveled way and shoulder. Where edge drop-offs will remain at the outside edge of fully paved shoulders and vehicles could have a wheel leave and return to the roadway, the edge is to be sloped at 1:1 or flatter and have a maximum height of ≤ 50 mm to help accommodate motorcycles and trucks.	
	Superelevation	Consult HDM §5.7.3. Identify where the recommended speed is less than design speed (use Section 2.6.1.1 of this manual). Improve superelevation (up to the maximum rate as necessary using AASHTO Superelevation Distribution Method 2) to have the recommended speed equal to the design speed. Where the maximum rate is insufficient, install advisory speed signs and consider additional treatments (e.g., chevrons, roadside clearing), as needed.	
The Following Are Additional Elements Where Multicourse Resurfacing (2R and 3R) is Recommended:			
	Superelevation	For Freeway projects, the superelevation is to be improved to meet the values in HDM Ch 2, Tables 2-13 or 2-14 (which utilizes AASHTO Superelevation Distribution Method 5).	
	Speed Change Lanes	Speed change lanes should meet AASHTO “Green Book“ Chapter 10 standards.	
	Clear Zone(s)	Establish based on HDM §10.3.2.2 A for non-freeway and HDM §10.2.1 for freeways.	
	Traffic Signals	Signal heads should be upgraded to meet current requirements. Detection systems should be evaluated for actuated signals and considered for fixed-time signals. New traffic signals that meet the signal warrants may be included.	
	Shoulder Widening	Shoulders should be widened to 0.6 m on local rural roads and 1.2 m on other nonfreeway rural facilities for motor vehicle recovery, bicyclists, and pedestrians.	
	Lane Widening	Non-freeway lanes may be widened per HDM §7.5.3. New through travel lanes are not permitted.	
	Design Vehicle	Intersections should accommodate the design vehicle without encroachment into other travel lanes or turning lanes.	
	Driveways	Driveways shall meet the spirit and intent of the most recent “Policy and Standards for the Design of Entrances to State Highways” in Chapter 5, Appendix 5A of this manual.	
	Turn Lanes	Turn lanes should meet the requirements of HDM §5.9.8.2	
	Curbing	Curbing must meet the requirements of HDM §10.2.2.4. For freeways, curbing that cannot be eliminated should be replaced with the 1:3 slope, 100 mm high traversable curb.	
	Drainage	Closed drainage work may include new closed drainage structures, culverts, and the cleaning and repair of existing systems. Subsurface utility exploration should be considered for closed drainage system modifications.	
	Pedestrian & Bicycle	Sidewalk curb ramps and existing sidewalks must meet HDM Chapter 18 requirements. Consider cross walks and pedestrian push buttons at signals. Minimum shoulder width of 1.2 m if no curbing.	
	Other		

Appendix II. PennDOT's Safety Improvements

Table A-2 Safety Improvements, Crash Type, and Implementation Criteria

Sources: (PennDOT, 2008)

Safety Improvements (Countermeasures)	Crash Type Prevented	Roadway Condition Criteria	Crash Reduction Factor (%)	Suggested 5-yr Threshold Crash Level	Average Crash Costs ($)	Fatalities (per 100 crashes)
Shoulder Rumble Strips	Single vehicle run-off-road crashes	Rural non Interstate state with >= 4 ft. paved shoulders	20 of run-off-road crashes	8 single vehicle run-off-road crashes	167,381.52	2.38
`Centerline Rumble Strips	Head on and opposing sideswipe crashes	State rural open access 22' or greater	25 of head on and opposing sideswipe crashes	3 head on and opposing sideswipe crashes	554,777.60	9.93
Centerline Rumble Strips	Head on and opposing sideswipe crashes	State rural restricted access undivided	25 of head on and opposing sideswipe crashes	3 head on and opposing sideswipe crashes	792,146.34	12.20
Centerline Rumble Strips	Head on and opposing sideswipe crashes	State rural open access undivided	25 of head on and opposing sideswipe crashes	3 head on and opposing sideswipe crashes	485,146.56	8.60
Centerline Rumble Strips	Head on and opposing sideswipe crashes	State rural restricted access divided	25 of head on and opposing sideswipe crashes	3 head on and opposing sideswipe crashes	706,229.51	14.75
Centerline Rumble Strips	Head on and opposing sideswipe crashes	State rural open access divided	25 of head on and opposing sideswipe crashes	3 head on and opposing sideswipe crashes	342,506.49	6.49

Table A-2 Safety Improvements, Crash Type, and Implementation Criteria (Cont'd)

Safety Improvements (Countermeasures)	Crash Type Prevented	Roadway Condition Criteria	Crash Reduction Factor (%)	Suggested 5-yr Threshold Crash Level	Average Crash Costs ($)	Fatalities (per 100 crashes)
Wider Centerline Markings	Head on and opposing sideswipe crashes	State rural open access 18-20 ft.	N/A	3 head on and opposing sideswipe crashes	374,017.06	6.56
Wider Centerline Markings	Head on and opposing sideswipe crashes	State urban restricted access undivided	N/A	3 head on and opposing sideswipe crashes	371,384.62	5.77
Wider Centerline Markings	Head on and opposing sideswipe crashes	State urban open access undivided	N/A	5 head on and opposing sideswipe crashes	161,163.63	2.30
Wider Centerline Markings	Head on and opposing sideswipe crashes	State urban restricted access	N/A	5 head on and opposing sideswipe crashes	569,245.35	11.34
Wider Centerline Markings	Head on and opposing sideswipe crashes	State urban open access	N/A	5 head on and opposing sideswipe crashes	153,418.85	2.17
Median Barrier/Edge Rumble Strips	Head on and opposing sideswipe crashes	State urban freeways	25 of head on and opposing sideswipe crashes	3 head on and opposing sideswipe crashes	569,245.35	11.34
Median Barrier/Edge Rumble Strips	Head on and opposing sideswipe crashes	State rural freeways	25 of head on and opposing sideswipe crashes	3 head on and opposing sideswipe crashes	721,955.36	14.29
Skid Surface Improvements	Wet pavement crashes	State rural non-intersection	50 of wet pavement crashes	8 wet pavement crashes and wet/total crash ratio >.30	169,311.69	2.46

Table A-2 Safety Improvements, Crash Type, and Implementation Criteria (Cont'd)

Safety Improvements (Countermeasures)	Crash Type Prevented	Roadway Condition Criteria	Crash Reduction Factor (%)	Suggested 5-yr Threshold Crash Level	Average Crash Costs ($)	Fatalities (per 100 crashes)
Skid Surface Improvements	Stop control intersection	State urban	50 of wet pavement crashes	8 wet pavement crashes and a wet/total crash ratio >.30	109,691.10	1.34
Skid Surface Improvements	Stop control intersection	State rural	50 of wet pavement crashes	8 wet pavement crashes and a wet/total crash ratio >.30	159,180.13	2.39
Skid Surface Improvements	Signalized intersection	State urban	50 of wet pavement crashes	8 wet pavement crashes and a wet/total crash ratio >.30	66,783.91	0.65
Skid Surface Improvements	Signalized intersection	State rural	50 of wet pavement crashes	8 wet pavement crashes and a wet/total crash ratio >.30	76,928.07	0.70
Guide Rail Upgrade	Strong post cable guide rail crashes	State urban	0, less severity	5 strong post cable guide rail crashes	106,550.00	1.25
	Strong post cable guide rail crashes	State rural	0, less severity	5 strong post cable guide rail crashes	105,150.16	1.28

Table A-2 Safety Improvements, Crash Type, and Implementation Criteria (Cont'd)

Safety Improvements (Countermeasures)	Crash Type Prevented	Roadway Condition Criteria	Crash Reduction Factor (%)	Suggested 5-yr Threshold Crash Level	Average Crash Costs ($)	Fatalities (per 100 crashes)
Guardrail Delineation	Night strong and weak post W-beam guide rail crashes	State urban	10 of night strong and weak post W-beam guide rail crashes	4 night strong and weak post W-beam guide rail crashes	173,821.87	2.95
Guardrail Delineation	Night strong and weak post W-beam guide rail crashes	State rural	10 of night strong and weak post W-beam guide rail crashes	4 night strong and weak post W-beam guide rail crashes	289,530.93	4.89
Guardrail Delineation	Night guide rail crashes	Local urban	10 of night guide rail crashes	4 night guide rail crashes	77,361.70	0.91
Guardrail Delineation	Night guide rail crashes	Local rural	10 of night guide rail crashes	4 night guide rail crashes	40,828.63	0.22

Appendix III. Top 150 Sections and Intersections

One of the common ways to identify the sites with potential for safety improvements is to analyze crash data. Each year the Office of Traffic Safety & Design generates a TOP 150 Sections and Intersections Report that ranks the sites (i.e., section and intersection) with highest improvement potential. The method used to develop top 150 hazardous site list is based on "Evaluation of Criteria for Safety Improvements on the Highway," a report published in 1966 by Roy Jorgensen and Associate (Jorgensen, 1966). For top 150 site selection, roadways are divided into categories, as shown in Table A-3. Intersections and road sections (mid-blocks) are categorized into eight types by different criteria, and the data is then processed separately. Note that Top 150 site selection is only applied to state maintained roadway (e.g., 18,000 centerline miles of roadways).

Table A-3 Data Categories in GDOT's Top 150 Procedures

Intersection	Road section (midblock)
• State Route with State Route, Urban, Signalized	• Rural interstate
• State Route with State Route, Rural, Signalized	• Urban interstate
• State Route with State Route, Urban, Unsignalized	• Rural 4 lanes, Divided
• State Route with State Route, Rural, Unsignalized	• Urban 4 lanes, Divided
• State Route with Other Route, Urban, Signalized	• Rural 4 lanes, Undivided
• State Route with Other Route, Rural, Signalized	• Urban 4 lanes, Undivided
• State Route with Other Route, Urban, Unsignalized	• Rural 2 lanes
• State Route with Other Route, Rural, Unsignalized	• Urban 2 lanes

The list of Top 150 is created by using the rate quality-controlled method described in the 1966 report. This method, which was originally used to evaluate the quality control of manufacturing industrial processes, uses a statistical test to determine if the crash rate at a particular segment is abnormally high in comparison to the crash rate of locations with similar roadway characteristics.

The frequency, rate, and severity safety indexes sort the crash data file and generate the appropriate reports; a final ranking report is produced based upon the previous three reports listing the top 150 worst locations in Georgia. A weighted scale is used to rank these locations.

The following formulas define the three indexes:

$$\text{Frequency index} = \frac{AverageFrequency}{CriticalFrequency} \tag{A-1}$$

$$\text{Rate index} = \frac{AverageRate}{CriticalRate} \tag{A-2}$$

$$\text{Severity index} = \frac{AverageSeverity}{CriticalSeverity} \tag{A-3}$$

where

Average Frequency= number of accidents/m,

Average Rate= number of accidents * 1000, 000 / number of days *s um of ADT, and

Average Severity= (10* number of fatalities + 4 * number of no visible + 2 * number of no complaint) / number of accidents.

The critical frequency is defined as follows:

$$\text{Critical Frequency} = \text{Average Frequency} + \text{k}\sqrt{averageFrequency} - \frac{1}{2} \tag{A-4}$$

The Critical Severity is defined like Critical Frequency.

Critical Rate, which is a roadway segment considered a high-crash location, is determined based on the average crash rate for a particular facility type and the vehicular exposure at the study location. Critical crash rates are calculated as follows:

$$R_c = \lambda + k\sqrt{\frac{\lambda}{m}} + \frac{1}{2m} \tag{A-5}$$

where, R_c is the critical rate for a particular location (crashes per million vehicles or crashes per million vehicles miles; λ is the average rate for all road locations of similar characteristics; m is the number of vehicles traversing a particular road section; k is the probability factor determined by the level of statistical significance desired for R_c (GDOT uses 95% significant level.)

The first two terms in Equation A-5 result from the normal approximation to the Poisson distribution. The last term of the equation is a correction factor because the Poisson distribution is a discrete distribution, whereas the normal distribution is a continuous distribution.

After index values have been computed based on the above equations, they are combined with user-defined weights. In other words, after the computations, each intersection and road section has an index value representing its estimated safety. Intersections and road sections are then grouped based on their located districts; totally, there are seven districts in the state. For each district, the corresponding hot spots are then addressed.

The aforementioned steps are illustrated in Figure A-1.

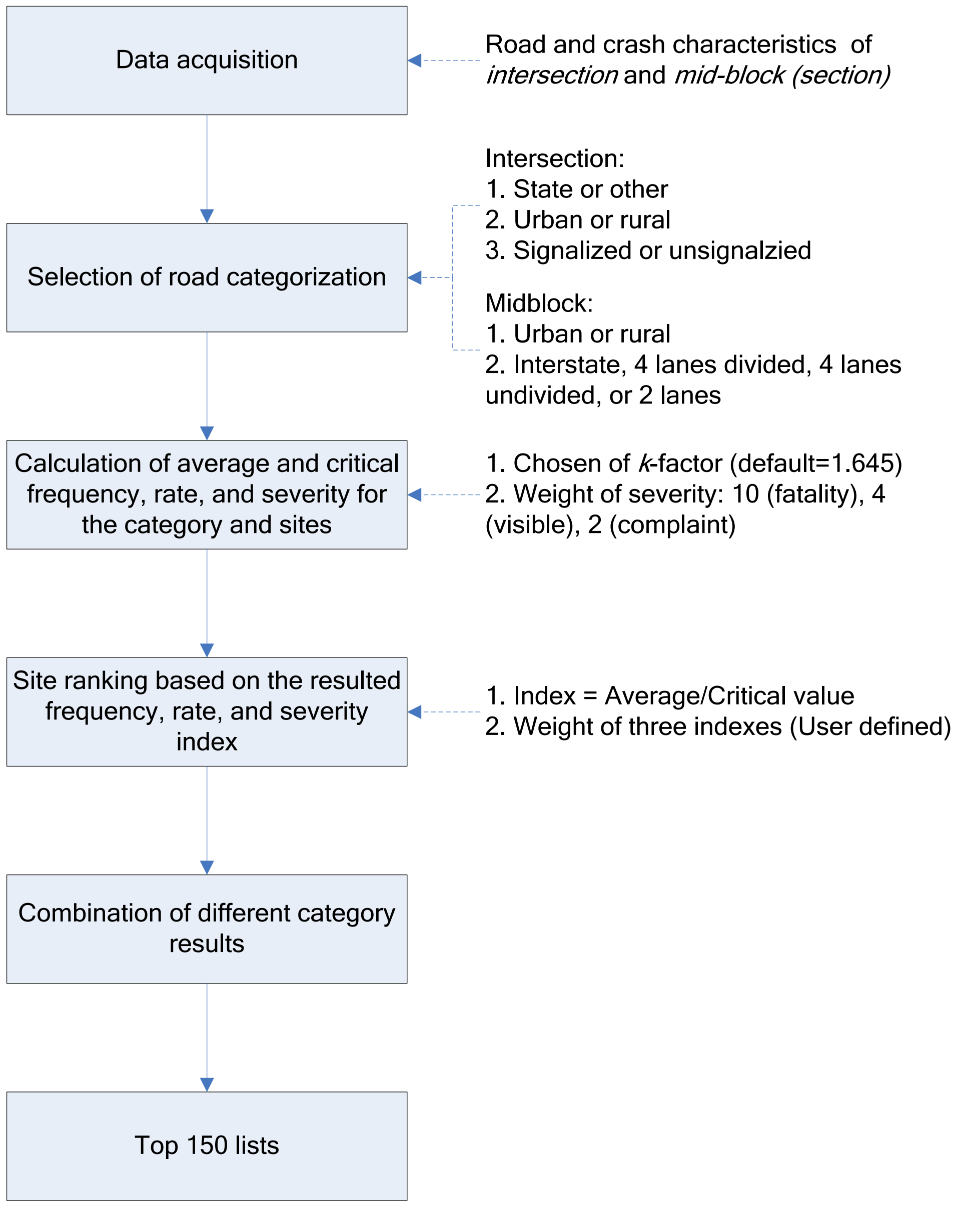

Figure A-1 GDOT Top 150 procedures