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Review of Literature and Maintenance Practices at State Transportation Agencies

Bryan Gibson
University of Kentucky, bryan.gibson@uky.edu

Nancy Albright
University of Kentucky, nancy.albright@uky.edu

Candice Y. Wallace
University of Kentucky, candice.wallace@uky.edu

Christopher Van Dyke
University of Kentucky, chrisvandyke@uky.edu

Doug Kreis
University of Kentucky, dougkreis@uky.edu

KENTUCKY TRANSPORTATION CENTER
176 Raymond Building, University of Kentucky
859. 257. 4513 www.ktc.uky.edu

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We provide services to the transportation community through research, technology transfer, and education. We create and participate in partnerships to promote safe and effective transportation systems.

Kentucky Transportation Center
176 Oliver H. Raymond Building
Lexington, KY 40506-0281
(859) 257-4513

www.ktc.uky.edu

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Review of Literature and Maintenance Practices at State Transportation Agencies

By

Bryan Gibson, Ph.D.
Program Manager

Nancy Albright, P.E.
Research Engineer

Candice Wallace, Ph.D.
Research Scientist

Chris Van Dyke, Ph.D.
Research Scientist

and

Doug Kreis, Ph.D., P.E.
Associate Director

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, KY

in cooperation with the
Kentucky Transportation Cabinet

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Table of Contents

Chapter 1 Literature Review 1
Chapter 2 KYTC Maintenance Background and Current Approach 10
  Background 10
  Current Approach to Maintenance Activities 12
    Field Operations Guide Manual (FOG) 12
    Maintenance Rating Program (MRP) 13
    Maintenance Guidance Manual 14
Chapter 3 State Approaches to Routine Maintenance and Inspections 16
  Utah 16
  Arkansas 19
  Montana 20
  Alabama 32
  Florida 38
  Key Takeaways 42
References 44

List of Figures

Figure 1: Delivery Approaches for Maintenance and Repair Programs 5
Figure 2: Asset Management Process 8
Figure 3: Performance Measures for Transportation Assets 9
Figure 5: KYTC Weekly Maintenance Crew Schedule 15
Figure 4: Layout of SSMH Activity Performance Standards 18

List of Tables

Table 1: Bridge Management Goals and Performance Measures 6
Table 2: Key Montana DOT Maintenance Activities 23
Table 3: Metrics Used by the Alabama DOT to Evaluate the Condition of Maintenance Features 33
Table 4: Alabama DOT Scheduling Guidelines for Maintenance Activities 35
Table 5: Target Maintenance Condition for Florida DOT Infrastructure Characteristics 39

Chapter 1: Literature Review

This chapter provides a brief overview of relevant literature related to maintenance scheduling, prioritization, and methodologies. Much of the literature on maintenance focuses on different approaches to preserving pavements, bridges, and other infrastructure. Some research has dealt with optimizing scheduling and funding to manage maintenance needs as efficiently as possible. Instead of reviewing all possible methods for conducting maintenance activities, we initially focus on the importance of maintenance before moving onto work about programming and scheduling guidance. These portions of the literature are most salient for this project.

A state transportation agency's (STA) maintenance function generally encompasses maintenance and operations. Wu et al. (2012, p. 1412) noted that "Since the 1960s, highway agencies in the U.S. have gradually moved from a focus on expansion to one on preservation." *Maintenance* is the routine care of infrastructure. Before an STA rebuilds, rehabilitates, or conducts preservation projects, it routinely executes fundamental tasks to optimize the highway network's condition. These tasks include but are not limited to: patching potholes, repainting roadway lines and markings, cleaning debris from water runoff ditches, washing salt off steel bridges, mowing, and picking up litter. *Operations* refers to all tasks that keep highway traffic moving. Operational items include but are not limited to: plowing and salting roadways; preserving signs, traffic signals, and roadway lighting in a state of good repair; removing dead animals in the roadway; and repairing damaged guardrails.

Maintenance is an important function of state transportation agencies. While other functions such as construction and rehabilitation are perhaps more visible, maintenance preserves current infrastructure in a state of good repair. The Federal Highway Administration (FHWA) differentiates between maintenance, routine maintenance, and preventive maintenance.[1] *Maintenance* "describes work that is performed to maintain the condition of the transportation system or to respond to specific conditions or events that restore the highway system to a functional state of operation." *Routine maintenance* is work "performed in reaction to an event, season, or over all deterioration of the transportation asset." Finally, *preventive maintenance* is "a cost-effective means of extending the useful life of the Federal-aid highway."

An STA's maintenance function is critical for ensuring that the transportation network operates safely and effectively. As the transportation network has grown, maintenance has become an integral part of keeping roads and bridges safe and in a state of good repair. With technological advancements redefining how transportation networks are maintained and managed, routine maintenance entails the regular upkeep of legacy networks as well as the effective deployment of new technologies. When agencies neglect upkeep of their assets, they deteriorate more quickly, often to the point where the only viable choices are to rehabilitation or replacement, which are more expensive options. Infrastructure that is routinely cared for remains in better condition longer. Maintaining assets in good condition extends their service lives and provides other benefits such as improved safety, fewer constituent complaints, less demand for expensive replacement projects, and improved traffic flow with fewer construction work zones.

Burningham and Stankevich (2005) cited several reasons why maintenance is important. Delaying maintenance drives up future maintenance costs or leads to even greater expenses for rehabilitation or replacement. Chang et al.'s (2017) scenario[2] analysis showed the impact of delayed maintenance manifests through "decreases of asset group condition over time; decreases of asset groups' remaining life; increases in agency costs in future years to recover the desired level of service; increases in backlogged costs over time; and decreases in asset value over time" (p. 1). Additionally, Burningham and Stankevich (2005) noted

[1] https://www.fhwa.dot.gov/preservation/memos/160225.cfm

[2] Scenarios included do nothing, delayed maintenance, and budget-driven maintenance; for a summary of Chang et al.'s scenarios across asset groups see Table 32, p. 63.

that drivers suffer increased economic burdens when they are forced to operate their vehicles on roads in poor condition. They divide maintenance into categories: routine, which are minor activities such as mowing and pothole repair; periodic, which demands more time and labor-intensive activities such as sealing; and urgent, which encompasses anything that requires immediate attention, such as landslides.

Burningham and Stankevich also listed several strategies for ensuring maintenance is a priority. When agencies focus on a core network of roads with high traffic counts it guarantees they receive sufficient maintenance attention. Next, agencies should clearly define who is responsible for maintenance, involve all stakeholders and coordinate approaches, and have standards for road maintenance. Maintenance plans should also give consideration to assets besides roads (e.g., bridges, signs, sidewalks). Finally, agencies need to establish clear objectives and plans for conducting maintenance given their level of funding. Maintenance needs should be addressed as soon as practicable because each day of delay adds to the overall cost.

State transportation agencies often struggle with the allocation scarce maintenance dollars. A critical issue STAs face is determining the effects of maintenance strategies on asset performance and service life (Chang et al. 2017, p. 3), which can instruct how they prioritize maintenance and allot funding. If maintenance activities are delayed, costs increase (Hicks et al. 2000), potentially leading to more extensive rehabilitation or even replacement. But undertaking maintenance too soon may result in unnecessary expenditures. As Zimmerman and Peshkin (2003, p. 3) contended, "preventive maintenance programs are cost-effective because they slow the rate of pavement deterioration, essentially delaying the need for major rehabilitation activities by several years." Needs-based budgeting is often used when performance data and prediction models are insufficient (Wu et al. 2008). Analyzing budgetary trade-offs between infrastructure types, Gharaibeh et al.'s (2006) demonstrated, using a case study from central Illinois, that decision makers are risk-averse and drawn toward projects and activities that have the most significant impact on safety and are publicly visible (e.g., bridges and intersections).

Pavements are among STAs' most important assets and require long-term planning for maintenance. Fwa et al. (2000, p. 367) described pavement management in the following way:

> An ideal pavement management program for a road network is one that would maintain all pavement sections at a sufficiently high level of service and structural conditions, but require only a reasonably low budget and use of resources, and not create any significant adverse impacts on the environment, safe traffic operations, and social and community activities. Unfortunately, many of these are conflicting requirements.

Balancing these priorities and requirements can apply to maintenance activities generally, however we focus first on pavements. Several approaches to pavement maintenance and management are reviewed in the following paragraphs.

Pavement Management Systems (PMSs)[34] are used often to identify areas for improvement and prioritize projects (Gurganus and Gharaibeh 2012, Wang et al. 2003). Agency goals are analyzed using a needs analysis (no budget constraints) and impact analysis (how funding will impact the network) (Haas et al. 1994, Smith 2002). Grivas et al. (1993, p. 25) pointed out that "Most PMSs include specific methodologies for characterizing pavement condition, identifying treatment options, predicting condition, and evaluating the economics." PMSs have several benefits (Zimmerman and Peshkin 2004, p. 13):

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[3] See Frangopol et al. (2007)
[4] For more on pavement management practices in some STAs see: https://www.fhwa.dot.gov/asset/pubs/hif11035/hif11035.pdf and https://www.fhwa.dot.gov/asset/pubs/hif11036/hif11036.pdf.

- Enhanced planning ability at all levels, including strategic, network, and project;
- Decision making based on observed and predicted conditions rather than opinions; and
- Ability to generate alternative scenarios of pavement conditions based on different budget projections or management approaches.

Observing that a key feature of all PMSs is the development of maintenance priority rankings, Ramadhan et al. (1999) sought to understand how stakeholders ranked the importance of maintenance activities. They surveyed various stakeholders (e.g., academics, highway and pavement maintenance department officials, engineers, qualified non-pavement individuals, and ordinary road), asking them to rank the importance of factors such as pavement condition, traffic, ride quality, safety, cost, classification, and overall importance of the road to the community. They found that the highest weighted priority was pavement condition, followed by safety, community importance, classification, traffic, and cost.

State transportation agencies use a variety of methods to prioritize pavement preservation projects (Gurganus and Gharaibeh 2012). Gurganus and Gharaibeh (2012) developed a decision support tool that uses six parameters (p.38) to rank pavement preservations projects:[5]

1. Visual distress
2. Average daily traffic
3. Current truck average daily traffic
4. Condition score
5. Ride quality
6. Section that receives most in-house maintenance

Applying their approach to a case study of a Texas Department of Transportation district indicated the results matched the actual prioritization decision 75 percent of the time. When projects match using the authors' method, transportation officials will be able to validate their decisions. If results do not align with traditional methods, officials have the potential to refine priority lists.

Some of the positive impacts of preventive maintenance programs for pavements are (Zimmerman and Pehskin, 2004, p. 14; Zimmerman and Peshking, 2003, p. 4):

- Delaying the onset of cracking
- Improving smoothness and surface friction
- Reducing moisture penetration
- Greater customer satisfaction
- Ability to make better-informed decisions
- More appropriate application of maintenance techniques
- Improved pavement conditions
- Increase in safety
- Reduction in overall costs

Combining preventive maintenance activities and pavement programs yield benefits as well (Zimmerman and Peshkin 2003). Zimmerman and Peshkin (2004, p. 20) listed several steps STAs could use to integrate maintenance activities and pavement programs.

[5] For more on pavement scoring methods and performance measures see Papagiannakis et al. (2009).

- Examine current capabilities in key areas where integration is likely to take place, including pavement-condition data collection, performance modeling, and treatment selection.
- Based on the information presented here, identify the gaps between current practices and needs.
- Develop a plan for implementation. The plan should address changes that will fill the integration gaps and the questions of whether and how any interim changes will be addressed.

Gao et al. (2012) analyzed maintenance issues as a bi-objective problem (see also Wu and Flintsch 2009), focusing on pavement condition improvement and budget utilization. They found the most effective way to identify optimal solutions was through use of a parametric method. Similarly, Guignier and Madanant (1999) developed an approach to optimize maintenance and (capital) improvements, which are generally treated separately due to different goals and budget allocations. However, efficiencies could be realized if tradeoffs between the two are calculated. Using a Markov decision model for joint optimization the authors found that savings can be realized through joint optimization and budget management.

Denysiuk et al. (2017) used a two-stage approach to address pavement maintenance in an effort to optimize scheduling, particularly for large networks. During the first stage, pavement sections within a network are collected and analyzed using a multi-objective approach; in the second stage, maintenance schedules for those sections are combined to develop an optimal maintenance plan. Validating this approach on a sample of Portuguese highways, the framework proved useful, indicating it could be used across other infrastructure asset types. Wu et al. (2008) leveraged a multi-objective approach to develop a decision-support model that considers maximization of service life and minimizing total cost, which helps support a needs-based budgeting approach to maintenance. Other researchers have also recognized that prioritizing pavement projects involves a number of potential goals and limitations, attesting to the benefits of using a multi-objective approach (Wu and Flintsch 2009, Fwa et al. 2000, Denysiuk et al. 2016, Wu et al. 2012).

Various analytical approaches such as multiple-criteria analysis, optimization techniques, performance measures and targets, benefit-cost analysis, decision trees, algorithms, and integer programming have also been used in attempts to prioritize pavement and other maintenance projects (Šelih et al. 2008, Frangopol and Liu 2007, Robelin and Madanant 2008, Medbury and Madanant 2014, Deshpande et al. 2009, Guerre and Evans 2009, Nuwirsii et al. 2006, Papagiannakis and Delwar 2001, Abo-Hashema and Sharaf 2009, Chan et al. 1994, Li et al. 1998, Wang et al. 2003). Cafiso et al.'s (2002) multi-criteria analysis identified five criteria that affect maintenance budget allocations: comfort, environment, safety, agency costs, and user costs. Chang et al. (2017) listed factors related to connecting maintenance and asset performance to consider (p. 3):

- Current asset condition;
- Timing of maintenance activities;
- Changes in asset condition created by the maintenance activity;
- Asset design features (e.g., materials, functionality, reliability);
- Performance measures;
- Communication needs (e.g., with funding entities);
- Expected levels of service;
- Mechanisms of deterioration over time;
- Expected asset service life; and
- Factors affecting the remaining asset service life (e.g., traffic volumes and loads, environmental conditions).

Hegazy (2006) examined different approaches to maintenance delivery, including conducting the maintenance in-house, using contractors, and a combination of both. Scheduling models using variables for in-house maintenance consider the availability of labor, work location sequencing, and time and cost associated with travel from one site to another. Hegazy observed that (p.26):

> An efficient delivery execution plan… is one that schedules the work at each site when its productivity is highest. As such, the execution order of various sites needs to be optimally decided, considering the time and cost of transporting resources from one site to the other.

Figure 1 (Hegazy 2006, Figure 2, p. 27) shows a breakdown of maintenance and repair projects with the best fit best in each category. Hegazy's approach allows for the use of outsourcing to develop cost-effective plans for maintenance and assist with deciding where and when the use of outsourcing can minimize costs.

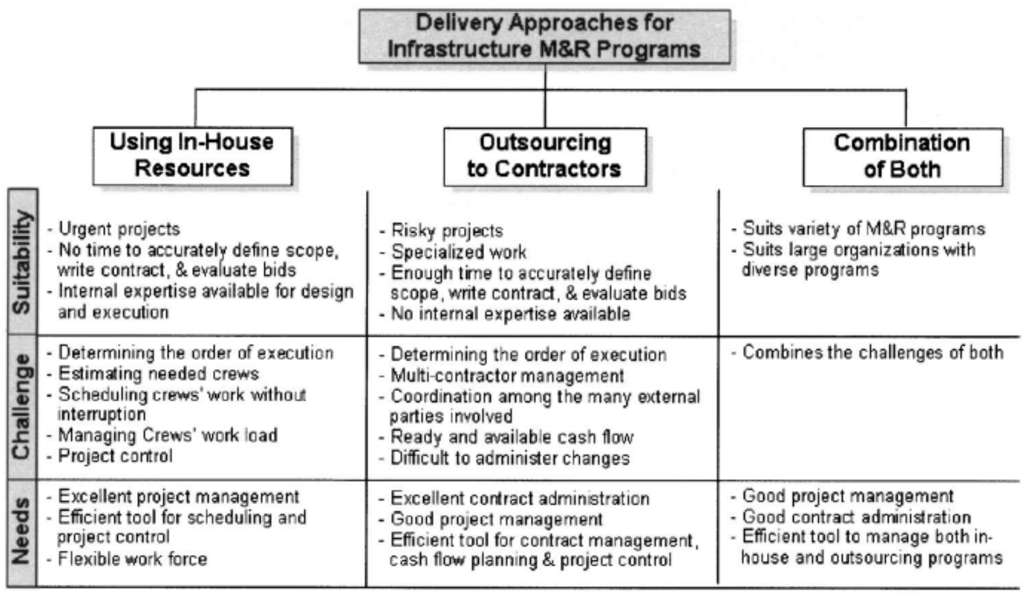

Figure 1: Delivery Approaches for Maintenance and Repair Programs

Moruza et al. (2017) developed a method to rank Virginia's transportation structures based on their importance to the highway network and the state's economy. The scores were termed *importance factors* (IFs), but they are not related to the condition or age of the structure in question. Not developed to exclude other measures such as age or condition, IF scores provide additional information to policymakers to consider as part of an overall formula approach: "The new formula incorporates independent, normalized, dimensionless variables that address functionality, risk, importance, condition (health index), and cost-effectiveness" (p. 20). Such information could be used help prioritize maintenance budgets. A key conclusion from the report was that:

> The IF score can be employed in conjunction with other tool scores that are based on physical condition data and cost-effectiveness to inform decision makers about which structures most justify priority funding and which structures are relatively less competitive for those funds (p. 28).

Similar to pavements, bridge management systems have also been developed (Thompson et al. 1998, Hawk and Small 1998, Miyamoto et al. 2000, Patidar et al. 2007). Pontis is likely the most recognizable example as it used by most STAs (Frangopol et al. 2001). Bridge management systems help STAs prioritize bridge maintenance needs and choose the most cost-effective option (Thompson et al. 1998, Hawk and Small 1998).

> Key functions of bridge management include the establishment of optimal investment funding levels and performance goals for an inventory of bridges, as well as identification of the appropriate combinations of treatment scope and timing for each individual bridge over its life cycle. (Patidar et al. 2007, p. 1)

Patidar et al. (2007, Table 1, p. 20) developed a set of bridge management goals and corresponding performance measures that can be used to evaluate activities (Table 1).

Table 1: Bridge Management Goals and Performance Measures

Goal	Performance Measures
Preservation of Bridge Condition	a) Condition Ratings (NBI 58-60, 62) b) Health Index c) Sufficiency Rating
Traffic Safety Enhancement	a) Geometric Rating/ Functional Obsolescence b) Inventory Rating or Operating Rating
Protection from Extreme Events	a) Scour Vulnerability Rating b) Fatigue/Fracture Criticality Rating c) Earthquake Vulnerability Rating d) Other Disaster Vulnerability Rating (Collision, Overload, Human-Made)
Agency Cost Minimization	a) Initial Cost b) Life-Cycle Agency Cost
User Cost Minimization	a) Life-Cycle User Cost

Researchers in Ohio developed the Ohio Bridge Condition Index (OBCI), which is an assessment tool for bridges (Fereshtehnejad et al. 2017). Using state bridge databases, the index "evaluate[s] bridges at the element, component, bridge, and network levels and reflect[s] the impact on the condition of the system of existing defects as well as maintenance, repair, and replacement actions for the condition enhancement of individual elements" (p. 152). Implementation costs of maintenance, rehabilitation, and replacement are considered along with structural and service failure costs. Providing usable information about bridge conditions assists with devising budget allocations, effective maintenance and replacement schedules, and communications with stakeholders, including the public. Noting that the "main objective of a bridge manager is to find the best maintenance plan for a group of bridges, or bridge components, over a prescribed time horizon" Neves et al. (2006a, p. 1005) developed a multi-objective analysis for bridge maintenance. The results showed that feasible solutions to managing bridge maintenance were possible when considering preventive maintenance and more extensive maintenance activities across a group of bridges. Liu and Frangopol (2004, 2005) also adopted a multi-objective approach that factored in bridge condition, safety, and cost. Morcous (2007) used Pareto analysis to optimize bridge preservation decisions in a way that minimizes life-cycle costs while maximizing bridge conditions, while Neves et al. (2006b) considered different maintenance plans including preventive activities as part of their approach.

Chang et al. (2017) established a framework for quantifying the impact of delayed maintenance on performance. Maintenance is typically delayed because of a lack of funding, investment policies that shortchange maintenance, a short-term planning horizon, the inability to quantify the effects of delayed maintenance, and lack of reports targeted at proper decision makers. Step one of their framework is to define the asset preservation policy which includes identifying the maintenance needed, performance metrics, and how maintenance decisions are made. Step two of this process is determining maintenance and budget needs. This step requires condition assessments, forecasting conditions, and identifying maintenance activities to meet objectives, which speaks to a focus on prioritizing maintenance activities and linking scheduling to performance metrics. Assessments vary across transportation assets and agencies, with different points of emphasis such as determining when the level of service falls below a certain threshold or performance measures are not being met (see Table 2, p.12 for examples). Chang et al. listed expected service life and inspection frequencies for common assets (Table 1, p.11). Pavement inspections are recommended annually, bridges and signs every 1-2 years, pavement markings biannually, culverts greater than 10 feet every 1-2 years, and concrete boxes every four years. While inspections are not necessarily a scheduling tool, they can identify areas that require further maintenance attention, thus allowing prioritization and scheduling efforts to be more informed while potentially matching to performance measures. Chang et al.'s framework incorporated needs analysis as well, which helps identify maintenance activities needed to meet certain targets or goals. Conducting needs analysis can help agencies prioritize and schedule various activities to achieve desired results. Chang et al. envisioned using their process to integrate asset preservation into an overall asset management process (see Figure 2), which relies on defining policy, needs, and analyzing the impacts of different maintenance approaches.

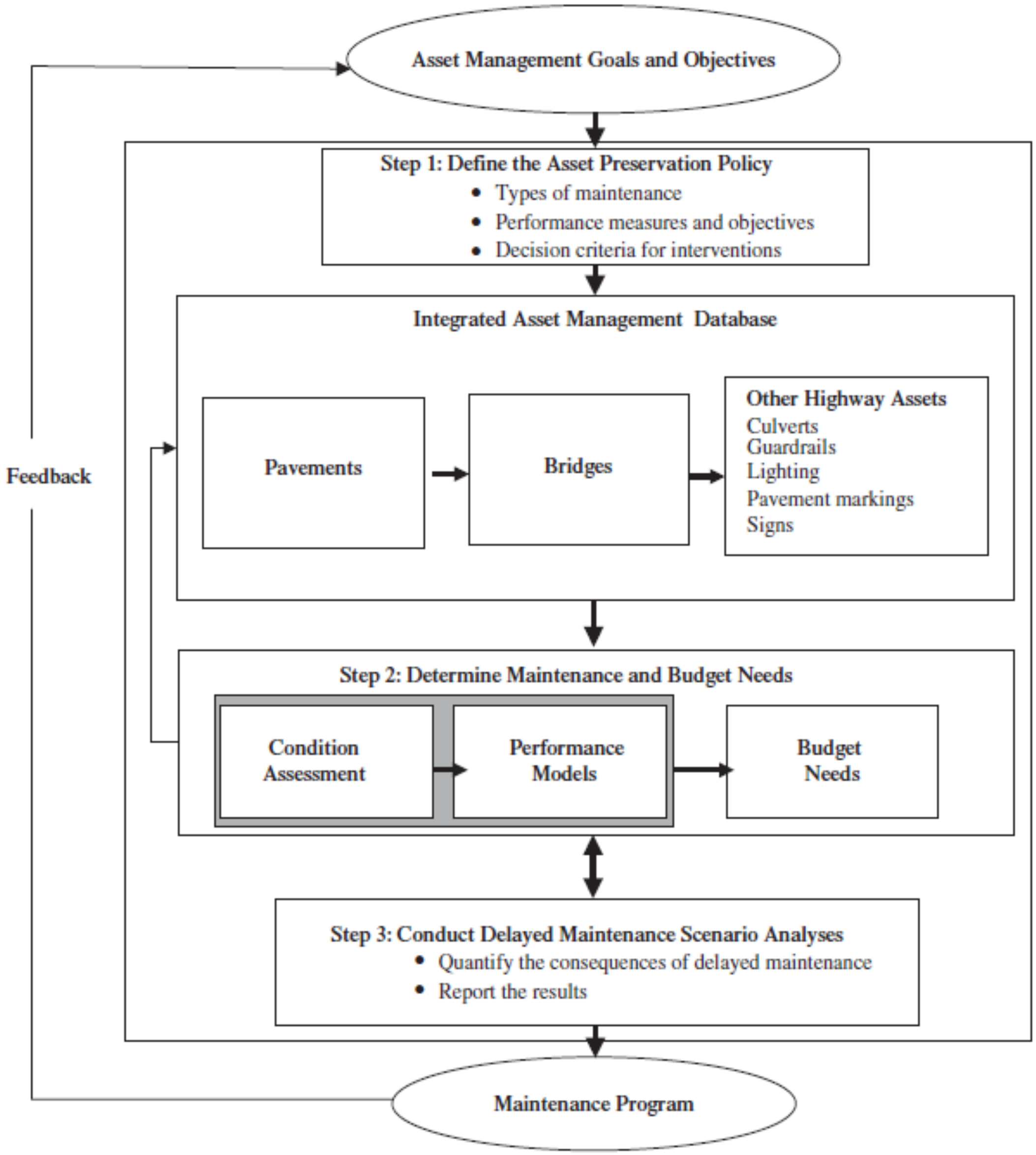

Figure 2: Asset Management Process[6]

Selecting performance measures for different asset classes can also produce valuable feedback on how maintenance activities are scheduled and prioritized. Chang et al. listed performance measures in their Appendix C that may be considered by when measuring the effectiveness, need, and frequency of various maintenance activities. Figure 3 presents a summary of strategic and network-level reports.

[6] Source: Chang et al. (2017), Figure 4, p. 20

Performance Measure Report Category		Pavement	Bridge	Culvert	Guardrail	Lighting	Pavement Marking	Signs
Asset condition		✓	✓	✓	✓	✓	✓	✓
Remaining service life		✓	✓	✓			✓	
Agency costs		✓	✓	✓	✓	✓	✓	✓
Asset value		✓	✓	✓	✓		✓	✓
Sustainability ratio		✓	✓	✓	✓	✓	✓	✓
Sustainability and users' costs [1]	Safety (e.g., accident costs)	✓	✓					
	Mobility (e.g., travel time, operating costs)	✓	✓					
	Environmental (e.g., CO_2 emissions)	✓	✓					

Figure 3: Performance Measures for Transportation Assets[7]

Deciding when maintenance is needed can hinge on pre-scheduled times and certain performance triggers based on asset condition. Models designed to predict asset condition yield valuable data about potential future maintenance needs, which can also be evaluated against performance metrics.

Preserving transportation infrastructure in a good state of repair is an important function of STAs. Maintenance programs help realize this goal by keeping infrastructure safe and extending its service life. Literature on maintenance focuses on the various management programs and objectives used to optimize scheduling and funding under certain conditions. Existing literature and models do not, however, account for special projects that arise and the fact that citizen complaints may receive foremost prioritization. The next two chapters review KYTC districts' current approaches to managing maintenance activities and the methods used by other states to organize and schedule maintenance activities. Understanding strategies used by other states will help contextualize the Cabinet's current practices and potentially generate ideas for improving its approach to maintenance.

[7] Source: Chang et al. (2017), Table 34, p. 64

Chapter 2: KYTC Maintenance Background and Current Approach

Background
KYTC's Maintenance function encompasses maintenance and operations as defined in Chapter 1. Maintenance and operations are the responsibility of the Department of Highways' Project Preservation units, which include the Division of Maintenance, the Division of Traffic Operations, and the district staffs dedicated to preservation. KYTC's Division of Maintenance contains five branches that cover corresponding maintenance and operations activities: Bridge Preservation, Operations and Pavement Management, Roadway Maintenance, and Roadside Maintenance and Permits. Bridge Preservation manages bridge inspections, bridge repairs, weight restrictions, bridge maintenance, the management program, and evaluates bridges on the Extended Weight Coal Haul Program.[8] Operations and Pavement Management handles data collection that provides information on the condition of assets, system performance, and maintenance budget needs. This branch houses several additional programs, including the Maintenance Rating Program (MRP), Operations Management System (OMS), Sign Management System (SMS), Pavement Management, and Intelligent Transportation Systems (ITS).[9] Roadway Maintenance attends to road maintenance contracts through the Contracting Section, Field Maintenance Section, and Traffic Section. Some of these include the statewide resurfacing program, pavement rehabilitation, new guardrail program, coordination of emergency and disaster work, slip and slide repair statewide coordination, statewide raised pavement markers and lenses, statewide panel sign repairs and statewide waterborne striping among others. Additionally, Roadway Maintenance works with district staff to review citizen concerns pertaining to state roadways.[10] Roadside Maintenance personnel focus areas between the road and fence as well as winter weather response. The Roadside Environmental Team oversees vegetation management programs, rest areas, and snow and ice activities including salt, environmental waste management, and guardrail recycling. It also assists districts with setting up contracts for inmate crews to perform roadside management support along state rights of way.[11] Finally, Permits reviews requests for road access and work on rights of way. Staff review and implement policies for utility installations; entrances and other correlated roadway modifications; altering or replacing existing drainage facilities; plantings on the right of way; replacing right-of-way fencing; locating facilities on rights of way; requests to conduct fairs, parades, festivals, banners, and welcome signs on rights of way; and new school site proposals on or near state roads.

The Division of Traffic Operations also provides maintenance and operations management and support throughout the state. Its three branches are Traffic Engineering, Systems Operations, and Traffic Design Services. The Traffic Engineering Branch provides statewide expertise and support for district requests regarding the proper application of traffic control devices and has primary responsibility for developing and implementing the Highway Safety Improvement Program. The System Operations Branch is responsible for the development of traffic signal timing and communications systems, while the Traffic Design Services Branch supports the development of traffic signal design plans.[12]

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[8] http://transportation.ky.gov/Maintenance/Pages/Bridge-Maintenance.aspx
[9] http://transportation.ky.gov/Maintenance/Pages/Pavement-and-Operations.aspx
[10] http://transportation.ky.gov/Maintenance/Pages/Roadway-Maintenance.aspx
[11] http://transportation.ky.gov/Maintenance/Pages/Roadside-Maintenance.aspx
[12] http://transportation.ky.gov/Traffic-Operations/Pages/default.aspx

KYTC's maintenance budget for fiscal year 2017 was programmed for $347.5 million; it increased slightly to $349.1 million for fiscal year 2018.[13] However, as Albright and Gibson (2017) noted, inflation has steadily eroded the maintenance budget's purchasing power, which impacts KYTC's ability to perform some activities and influences the frequency of others. This does not include funding sources that affect infrastructure conditions such as the federal bridge replacement and state resurfacing programs. Table 2 (Albright and Gibson, 2017, p.10) details some of the various maintenance activities covered by the maintenance budget.

Table 2: Description of Maintenance Categories

Snow and Ice – Training driver simulations, calibrating equipment, preparing equipment for winter, in-house labor and equipment during winter storms, salt and calcium chloride materials, and payment for contractor support.
Bridge maintenance – Equipment, labor and materials needed to complete minor repairs such as joint sealing, concrete patching, waterproofing, steel cleaning and patching, and cleaning debris on and around the structure (bridge inspection and larger maintenance projects are funded separately).
Mowing – State forces and equipment as well as contractor support for mowing and trimming.
Drainage – Cleaning and repairing pipes under the pavement and under access points, cleaning culverts, reestablishing roadside ditches, and pump station maintenance.
Rockfall/Landslide – For minor rockfalls and landslides: the material, labor and equipment necessary to remove the debris, as well as protect and reestablish the slope (major slips and slides that require a geotechnical analysis will typically be funded separately).
Tree/Brush – Pruning or removing trees and shrubs along the right of way, treatment of stumps to prevent regrowth, and removal of trees that may originate off right-of-way but present a danger to the traveling public.
Litter/Debris/Sweeping – Contractor payments, inmate crew support, removal of animal carcasses and other debris on the pavement, and sweeping debris from the roadways and shoulders.
Weed Control – Spraying for noxious weeds listed in and as required by KRS 176.051, spraying herbicide around guardrail, training and calibration on proper use of the pesticide equipment, and other spraying as needed for vegetation control.
Guardrail Repair – Repairs made to longitudinal guardrail, crash cushions and end treatments by state forces or by contractors. Reimbursement is sought when the damage is the result of a known crash. However, those funds cannot be restored to the maintenance budget and are deposited to the general road fund instead.
Rest Areas – Custodial efforts and landscape management either by state forces or contractors and the inspection of work performed by contract (does not include utility expenses, larger repairs, and weigh station services).
Pavement Patching – Patching beyond potholes, such as strip patching and milling, for both the driving lanes and the shoulders.
Potholes – Pothole repairs on the driving lanes and shoulders.
Striping – Restriping work on the edge lines and lane lines.
Signs – Fabrication and installation of replacement sheeting and panel signs, either by state forces or contractors (does not include signs contained in construction contracts).
Signals and Lighting – Traffic signals and controllers, roadway lighting, overhead changeable message signs, navigation lighting, and aviation lighting.

[13] http://transportation.ky.gov/Budget-and-Fiscal-Management/Documents/General%20Assembly%20House%20Bill%20304.pdf

Current Approach to Maintenance Activities
KYTC has three guidance publications to assist with planning with work of the maintenance crews:

- Field Operations Guide,
- Maintenance Guidance Manual,
- and the Maintenance Rating Program.

Each document assists district managers with directing work needed in the coming year and deciding on the best method of execution.

Per the Maintenance Guidance manual, the Department of Highways "maintain(s) all roads, streets, and bridges that are or have been accepted into the State Highway System by official order of the Secretary." To fulfill that requirement, the Department staffs 124 county-level maintenance crews (three counties have more than 1 crew). A variety of specialized crews within in each district perform more specialized maintenance duties (e.g., traffic signal, signs, bridge and roadside crews). County crews offer a broad spectrum of support for the 100-400 roadway miles they are assigned. These crews address maintenance that are not delegated to special crews or a contractor within their geographic area of responsibility. While those responsibilities vary throughout a year and may differ among districts based factors such as topography and geography, there are several duties that are similar in both how they are conducted and how frequently they are needed. Most of those similar duties are outlined in the Cabinet's Field Operations Guide, a policy manual dedicated to the consistent performance of those similar responsibilities.

When crews perform a maintenance activity, the date(s) of performance, roadway sections treated, labor power, and materials and equipment needed to accomplish the task are captured in the Cabinet's Operations Management Software (OMS). OMS does not provide guidance but is the common reporting standard for maintenance work. The Cabinet is frequently asked to provide the amount of money spent on various activities or in a specific geographic area. The use of OMS lets Cabinet personnel respond to those requests quickly and confidently. Documenting this information also assists the Highway Department in determining how and where resources are being used. As the Cabinet implements asset management practices, having reliable data on where and at what cost regular maintenance is done, will help it provide the anticipated outcomes based on the budget provided.

The Maintenance Rating Program (MRP) catalogues maintenance work outcomes by documenting whether the Cabinet is meeting expectations for various maintenance categories. It provides a window into whether crews are doing enough work on various types of activities. But it does not offer guidance on when or how frequently to perform an activity. While the MRP is a statistically valid snapshot of the Cabinet's maintenance activities, it only provides high-level direction on work programing.

Field Operations Guide Manual (FOG)
The FOG lists 81 distinct activities and groups them into 13 major categories of work. Some of the 81 activities are similar, but differ slightly based on whether state forces or a contractor performs the work. Several activities must be done to preserve roadway safety and are executed as soon as the Cabinet is made aware of the need, (e.g., snow and ice operations, repairing damaged guardrail or a break in the pavement). Other activities are important and can be scheduled around those critical activities based on the priorities of the season and the topography.

The FOG outlines many factors to consider when scheduling routine maintenance activities. The entry for each activity includes the following information:

- A written description,

- The typical crew size,
- Equipment needed,
- Procedures for how the work should be completed,
- How the activity will be entered in OMS,
- Recommended materials,
- Environmental considerations associated with the activity, and
- The typical funding source for the activity.

Outside of maintenance operations applied directly to roadways, the FOG also contains training activities and activities required to maintain environmental compliance on maintenance lots. Within each category, there is generally a miscellaneous activity code used for activities done so infrequently they do not require a pre-assigned activity code. While there is information on performing and documenting the activities, the only information on when or how often to perform them is a scheduling description, which accounts primarily for weather-related restrictions.

Maintenance Rating Program (MRP)

The Maintenance Rating Program (MRP) is a systematic measurement process that uses roadway condition surveys to support maintenance planning decisions. KYTC has used the MRP since 1997 to gauge, for 23 outputs of maintenance work, whether it is meeting its internal expectations and the expectations of motorists. Each year, the Cabinet gathers data for approximately 4,000 500-foot road segments. This number of segments offers a statistically valid snapshot of the condition of the state's roadways and therefore the quality of maintenance work done at the statewide and district levels. The final score for each 500-foot road segment evaluated is based on a cumulative assessment of the 23 outputs. The highest possible score for each segment is 100. Overall the Cabinet strives for a collective score of 80. Every three years there are sufficient new data to generate a statistically valid representation of county-level performance. To accomplish data collection, staff in each district are trained on how to collect the data; a field guidebook illustrates of how to calculate scores for each category. Approximately 10% of the segments are checked by Division of Maintenance staff to ensure consistent data quality and grading statewide. At the highest levels MRP data can provide guidance on tasks maintenance crews may need to focus additional effort in the coming year. Likewise, it indicates areas where the maintenance forces may be striving for (and attaining) a higher level of service than is cost-effective.

Final performance scores are compared to customer expectations (based on customer surveys). KYTC uses results from the customer survey to calibrate the weights and performance goals in the MRP scoring process to align with the value taxpayers accord to various components. Conducted in 2010, the most recent survey indicated customers assign the highest priority to pavement surfaces, signs and markings, and roadside drainage. The highest perceived maintenance needs (which are given the highest weights) were signs, guardrails, and striping while the lowest were pavement surfaces, shoulders, and drainage.

Maintenance Guidance Manual

The Maintenance Guidance Manual contains policies related to the activities county crews perform. According to Section 205 of the manual, "Maintenance crews shall perform the following functions as directed (and in varying degrees) on all roads and rights of way on the state-maintained system in each assigned territory." Section 205 describes 18 areas of responsibility and the activities to be done under the auspices of each. Section 207 directs maintenance employees to perform several formal and informal inspections. Informal inspections primarily consist of staff being attentive to conditions within their area of responsibility and reporting deficiencies to the Section Engineer so that corrective work can be scheduled. The Division of Maintenance performs the following formal inspections: cross drain and culverts, pavement inspections on Parkway and Other Non-Interstate Controlled Access Facilities, interstate conditions, and highway fill dams. Bridge inspections are undertaken primarily at the district level with annual reporting, quality assurance reviews, contract assistance and larger team inspections being initiated at the Division of Maintenance. Despite this guidance, many daily and weekly maintenance activities are dictated based on complaints, management-based priorities and the weather or other emergency response generators. Some attempts have been made at scheduling maintenance activities. Figure 5 shows an example of a weekly schedule provided to the research team by a former maintenance engineer.

WEEKLY CREW SCHEDULE

CREW #			**Total Crew:**					**WEEK OF:**										**Scheduled By:**				
		Job #1				**Job #2**				**Job #3**				**Job #4**				**Job #5**				
Day of Week	Planned vs. Actual	Act Code	Crew Size	Route Number	Accom	Act Code	Crew Size	Route Number	Accom	Act Code	Crew Size	Route Number	Accom	Act Code	Crew Size	Route Number	Accom	Act Code	Crew Size	Route Number	Accom	**Remarks**
Monday	Planned																					
	Actual																					
Tuesday	Planned																					
	Actual																					
Wednesday	Planned																					
	Actual																					
Thursday	Planned																					
	Actual																					
Friday	Planned																					
	Actual																					
Alternate	Planned																					
	Actual																					
Alternate	Planned																					
	Actual																					
Alternate	Planned																					
	Actual																					

Figure 4: KYTC Weekly Maintenance Crew Schedule

Chapter 3: State Approaches to Routine Maintenance and Inspections

To deepen our understanding of how state transportation agencies around the U.S. execute their maintenance programs, we conducted a review of policies, guidance, and other published resources of select agencies. Although the maintenance programs of all state agencies were briefly examined, we limit our discussion in this chapter to five, which were selected based on the accessibility and completeness of their information and relevance to this project. Our focus stayed fixed on routine maintenance activities throughout, and that is what this chapter reports on. Routine maintenance encompasses activities such as patching potholes; rejuvenating striping and other pavement markings; sign installation and repair; inspecting and clearing pipes, culverts, and drainage outlets; and vegetation management; among others. Most agencies regard winter maintenance operations (e.g., snow and ice removal) as part of their routine maintenance program. However, as this is not a primary emphasis of this project, material regarding winter maintenance has been omitted. For each state, we discuss the divisions and personnel responsible for conducting maintenance, note key guidance documents, describe their procedures for scheduling maintenance activities, and present an overview of inspection programs that inform maintenance. While some agencies conduct some maintenance activities at regular intervals, others do not, or they state the performance of maintenance hinges on the results of inspections, or that maintenance is done on an as-needed basis. Most agencies, to some extent, tie their maintenance agenda to their inspection programs. Where available, scheduling intervals are included in the following narratives and tables.

Utah

At the Utah Department of Transportation (UDOT), all managers in the Maintenance Division, from the Director of Maintenance to Station Supervisors, are responsible for "[providing] the planned level of maintenance service in a manner that places continuing emphasis on the economic utilization of personnel equipment and materials." The agency's published guidance documents review its approach to maintenance. The most detailed information is found in the *Station Supervisor's Maintenance Handbook* (hereafter SSMH) and the *Maintenance Management Quality Assurance Plus Inspection Manual*[14].

The SSMH contains targeted guidance for Station Supervisors on the maintenance planning process, the scheduling of maintenance activities, and activity standards. UDOT has adopted a five-step, semi-cyclical process for planning and scheduling maintenance activities. The steps include: 1) planning, 2) identifying work needs; 3) scheduling activities; 4) following the accepted schedule; and 5) updating specific work needs. All annual work needs are planned for in the Annual Work Program, which is put together by Station Supervisors, Area Supervisors, and Maintenance Engineers. During the planning phase, a monthly activity schedule is created and stored in UDOT's Operations Management System (OMS). Next, Station Supervisors identify work needs from a review of various sources, such as the approved annual work plan and budget, semi-annual inspections, complaints, field reviews, MMQA+ reports (see below), and OMS work requests. Scheduling maintenance activities is a three-step process. First, Station Supervisors enter the station work plan into the OMS; information entered in the system includes the activity, required labor, equipment and materials needed, and anticipated outcome. Once Station Supervisors input station work plans into the OMS, Area Supervisors are responsible for coordinating station schedules according to priorities and resources available within the area. After they obtain approval from Area Supervisors, Station Supervisors prepare and distribute work schedules. The fourth step in planning and scheduling maintenance is following the schedules. While a schedule should be hewed to as closely as possible, Station Supervisors have the discretion to rearrange schedules if exceptional circumstances warrant it. For example, accidents; hazardous weather; emergences; unsafe roadway conditions or a change in the availability of staff, equipment, or material may compel schedule changes. Lastly, schedules are updated each week to reflect a station's current needs. Again, Station Supervisors are responsible for these updates and Area Supervisors are tasked with approving them. UDOT deems scheduling efforts a success if between 75 and 80 percent

[14] See UDOT (2012) and UDOT (2017) for more detailed information.

of scheduled work is completed as planned and on time. The SSMH also contains practical tips in its section on scheduling focused on improving workflows and optimizing the use of assets and resources (see UDOT 2012, pp. 8-10).

The second portion of the SSMH contains activity standards for all maintenance tasks crew may be required to perform. Section Supervisors are instructed to review activity standards carefully and adjust schedules and work assignments according to project context. For example, the number of planned crew could be revised upward or downward in response to travel distance, special safety requirements, unique traffic control needs, or idiosyncratic job site requirements. All maintenance work should conform with the activity standards, although there may be some occasions where deviations are necessary (e.g., emergency conditions, experimenting with a new method or procedure at the request of UDOT executive staff, unusual traffic conditions). The SSMH warns against departing from activity standards unless it is absolute necessary because doing so results in inappropriate levels of service, budget overruns, and poor productivity. Activity standards fall into one of ten categories: 1) Snow and Ice Control, 2) Hard Surface, 3) Non-Hard Surface Maintenance, 4) Roadside Maintenance, 5) Vegetation Control, 6) Drainage and Slope Repair, 7) Major Structure Maintenance, 8) Traffic Services, 9) Support, and 10) Rest Area Maintenance. Standards are further subdivided into three activity types: *S Activities*, which require station approval; *D Activities*, which call for District Engineer approval, and *M Activities*, which are administrative and require District Engineer approval. The remainder of the SSMH consists of activity performance standards, or spec sheets (Figure 5 is a sample spec sheet). Each standard catalogues the following — a work description; a scheduling calendar, which indicates during which months an activity can take place; conditions for scheduling; average daily production; recommended procedure; personnel type and quantities; equipment and quantities; material and quantities; and a description of how activity quality is measured.

UTAH DEPARTMENT OF TRANSPORTATION
MAINTENANCE DIVISION
ACTIVITY PERFORMANCE STANDARD

Work Activity:	**7D13 - Bituminous Surface and Shoulder Maintenance (Special)**			**Activity ID:**	**7D13**
MMQA Group:	**2A1**	**Description:**	**Bituminous Surface and Shoulder Maintenance (Special)**		

Work Description:

Work where the quantity planned does not fit the guidelines of the other hard surface and shoulder activities. In most cases the accomplishment would be less than 7D07, 7D08, 7D09, 7S02, etc

Calendar:

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun

Conditions for Scheduling:

Temperature requirements restrict effective surface replacement to the warmer months. Major emphasis should be exerted during the months April through September

Average Daily Production:	300	**Accomplishment Unit:**	Square Yards

Recommended Procedure:

1. Call Bluestakes if any excavation is required 48 hours before working
2. Notify local agencies and/or business.
3. Perform a project driver through to identify all aerial obstructions.
4. Mark with signs all overhead utilities crossing the road 50' on either side of crossing.
5. Use a spotter when working in the crossing zone.
6. Place safety devices and signs (See Standard Drawings).
7. Remove deteriorated surface
8. Brush or spray tack oil on vertical and horizontal surfaces to provide a bond between the existing surface and the bituminous premix material being placed
9. Dump or hand place bituminous premixed material in area
10. Level bituminous premixed material to original line and grade (x-section) with equipment or with hand tools
11. Roll area to proper compaction
12. Clean up material removed from deteriorated area
13. Re-establishment of striping shall be completed at the end of each day's operation
14. Remove safety devices and signs

Personnel	Qty.	Equipment	Qty.	Material	Code	UOM	Qty.
People	5	0104 - Truck, Tandem Axle. SRE	1	Hot Plant Mix 9.5 (3/8") 58-22	74512150040	Metric Ton	19
		0501 - Grader, Standard	1				
		0902 - Loader, FE up to 2 Yard	1	Liquid Asphalt SS or CSS Concen	74508151409	Gal	15
		1001 - Asphalt Dist, Trailer, 600 Gal	1				
		1803 - Roller, Self Prop, 3 to 6 Ton	1				
		3002 - Lease Truck, Pickup, 3/4 Ton	1				
		3011 - Lease Truck, 1 Ton, Dual Wheel	1				
		3502 - Platform Trailer, 5-15 ton	1				
		Traffic directional control devices may also be used if co					

Measure of Quality:

1.

Figure 5: Layout of SSMH Activity Performance Standards

First established in 1997 to establish statewide protocols for evaluating and reporting on the effectiveness of UDOT's maintenance program, the Maintenance Management Quality Assurance Plus (MMQA+) acquired its current form in 2003 and underwent revisions in 2012. The principal goal of MMQA+ is to improve the agency's efforts to report on how well it is preserving the state's infrastructure. Information collected as part of the program informs budget development and highlights areas in which more or fewer resources could be allocated. The program also helps UDOT set targets for future maintenance levels after accounting for available budgets and resources. While MMQA+ is instrumental for statewide maintenance programming, it is also critical at the station level for helping to prioritize and schedule activities. Using MMQA+ reports, Station Supervisors evaluate what activities in their station should receive priority based on an examination of current conditions, performance targets, and funding.

The MMQA+ program measures and reports performance with respect to level of maintenance (LOM). Letter grades (i.e. A, B, C, D, F) are used to designate LOM. At the state level, each activity covered by MMQA+ is assigned a target LOM. While target LOMs vary among activities, they generally range from A to C. The *MMQA+ Inspection Manual* cautions that target LOMs are not binding. Rather, the goal is to maintain a facility as close to the target LOM as possible while neither falling short nor exceeding it.

UDOT's strategic goals, the current LOM, available funding and resources (e.g., labor, equipment, materials), public feedback (e.g., customer survey results), and input from district engineers and department leaders all influence the LOM chosen for specific activities. Data collected during inspections enable UDOT to optimize resource allocation so that resources are shifted toward maintenance activities failing to meet their targets and away from those where target LOMs are being exceeded.

The *MMQA+ Inspection Manual* lays out standards for evaluating the following maintenance activities — 1) snow and ice control; 2) non-hard surface maintenance (shoulders, curbs, gutters); 3) roadside maintenance (litter, fences); 4) vegetation control (weeds, vegetation obstructions); 5) drainage and slope repair (grading and cleaning ditches, maintaining inlets and outlets, erosion repair); 6) traffic services (pavement striping retroreflectivity, pavement messages, repair and replacement of signs and delineators, guardrails, sweeping); and 7) rest area maintenance. MMQA+ does not outline standards for maintaining or evaluating the performance of asphalt or concrete pavements, structures (e.g., bridges), or intelligent transportation systems, among others. MMQA+ evaluations occur at the station level. Station personnel divide routes into one or more segments and then use the published guidelines appraise the condition of each route segment. During the inspection, they record the number of features requiring maintenance within an activity subgroup as well as the number of deficient features. Inspection data are loaded into MMQA+ software, which is part of the OMS software package, and used to aid in decision making about maintenance. Except for snow and ice control and rest area maintenance, measurements are taken twice per year. The MMQA+ program has a quality assurance component as well, and each station is audited once per year. The Quality Assurance Coordinator is responsible for compiling a list of stations to audit during an inspection season and then using a statistical methodology selects route segments and MMQA+ measures to independently validate. Once the segments and measures have been chosen, a quality assurance team inspects the routes and compares their ratings to those of station personnel. Following the inspection, the quality assurance team meets with station personnel to go over its findings. If discrepancies exist between the inspection team's scores and the station personnel's score, they discuss why the variance exists and work to, in UDOT's words, "calibrate [their] eyeballs." While the measurements require subjective judgment, the agency's goal is to achieve statewide consistency in how maintenance activities are evaluated. In addition to reviewing the MMQA+ program, the inspection manual contains instructions taking MMQA+ measurements. For each measurement, the manual includes a description of what is to be measured, notes on the desired condition, a description of what constitutes a deficient condition, and reporting guidelines. The reporting guidelines contain directions on measurement frequency, measurement area, reporting deficiencies and overall condition, and instructions for making supplemental comments. Representative illustrations accompany each section and provide examples of features in a desired condition and those in a deficient condition.

Arkansas

The Arkansas Department of Transportation (Arkansas DOT) defines maintenance activities as work that is intended to preserve the state's highway and structure system. While many activities are scheduled in advance, some are performed on an ad hoc basis (e.g., asphalt patching may not require pre-planning in some cases). The *Maintenance Supervisor's Manual* (Arkansas DOT, undated) gives insights into Arkansas DOT's approach to maintenance and the strategies it uses to plan, schedule, and perform maintenance. Up front, it contains a list of functions for maintenance, including activity codes, a description of the work associated with each task, and work units. The agency divides its maintenance activities into the following categories: routine surface and shoulder maintenance; authorized surface and shoulder maintenance; routine roadside and drainage maintenance; authorized roadside and drainage maintenance; chemical weed and grass control; routine structure maintenance; routine traffic services; authorized traffic services; unusual or disaster maintenance; other services; and general maintenance. Maintenance functions are grouped into four work categories: routine unlimited maintenance, routine limited maintenance, special authority maintenance, and betterment work. For routine unlimited maintenance, work needs vary throughout the state and across the year. It is generally not possible to accurately predict the amount of work that falls within this category; the category also includes the correction of unsafe conditions, where work must be done to keep the roadway system operational. Agency personnel plan for work quantities for activities qualifying as routine limited maintenance. Because of the nature of these activities, it is atypical for amount of the routine limited maintenance performed to exceed what has been planned for. Special authority maintenance consists of large-scale maintenance activities, specialized tasks for which most crews lack the equipment or labor power needed to execute. When planning special authority maintenance activities, district maintenance engineers and district supervisors coordinate details about materials and loaning equipment. Lastly, betterment work includes activities geared toward improving roadway facilities to a condition better than their originally constructed state. Activities in this category are far-ranging, from small improvement efforts to ambitious projects that require the use of special crews. Supervisors coordinate betterment projects, while district-level crews are usually responsible for their implementation. In some cases, area crews are brought in to assist. Betterment projects are paid for out of district maintenance funds of special project funds. The Maintenance Division prepares annual work programs for each district. Work programs serve as the foundation for determining how much work will be carried out during the next year as well as the number of staff required for each crew and establishing a budget to complete needed work. Program content also depends on the allocation and types of responsibilities in each district, the assessed condition of roads and buildings, rest area usage, and number of mowable areas.

Maintenance personnel work across three levels — statewide, district, and county. Each level includes maintenance supervisors who are tasked with scheduling and executing a portion of the total maintenance work. Typically, activities fall within the purview of a single level, but there are some activities maintenance staff at all three levels participate in (e.g., maintaining traffic signs). Each year, job superintendents and area maintenance supervisors (commonly referred to as just *supervisors* in Arkansas DOT literature) receive a performance summary that includes the types and amounts of maintenance slated for their assigned area during the upcoming year. Work quantities are set annually at planning meetings held in districts each spring. As noted, there is an annual schedule developed for maintenance activities, which specifies when tasks are to be accomplished. Ideally, supervisors schedule maintenance activities one to two weeks in advance of their performance. And in some cases, planning occurs at the district level through a consultation between supervisors and district maintenance engineers. Supervisors prepare biweekly planning worksheets to assist with scheduling and organizing activities; once completed, these worksheets are reviewed and approved by district maintenance engineers. Additionally, supervisors are responsible for continuously inspecting routes and facilities located within their jurisdiction; they are also required to conduct two night inspections per year. The *Maintenance Supervisor's Manual* contains instructions on scheduling and outlines scheduling responsibilities for area maintenance supervisors and district maintenance engineers. The manual also provides comprehensive maintenance standards, which offer instructions on carrying out maintenance tasks. Each activity standard includes the following components: activity definition, guidance on identifying issues, concise directions for performing the maintenance, supplemental comments, a list of crew and equipment required to complete the activity, materials and tools needed, and information on daily production and productivity. Activity standards do not indicate how often each activity should be done or specify an inspection cycle for assessing infrastructure condition to determine whether any maintenance is necessary.

Montana

The Montana Department of Transportation (MDT) defines maintenance as those "tasks and subtasks performed by one crew at one location of the highway system at one time to keep the highway at a specific quality level." (MDT 2002, p. 9). MDT's published maintenance manual describes maintenance activities and expectations for each. The manual is structured around discrete activity types. As such, it contains separate chapters on the agency's eleven activity groupings: 1) Asphalt Pavement Program; 2) Concrete Pavement Program; 3) Roadway/Roadside Maintenance; 4) Roadside Cleanup Program; 5) Maintenance of Facilities; 6) Guidance, Safety Devices, and Road Closures; 7) Winter Maintenance Program; 8) Structure Maintenance Program; 9) Materials Production Program; 10) Equipment Inspection, Operation, Preventive

Maintenance, and Repair; and 11) Emergency Procedures. Each chapter begins with a brief introductory section that describes in broad strokes the activities that fall within its respective grouping (and which receive more detailed treatments later on). The introductions proceed to discuss the types and purposes of the maintenance tasks, explicitly stating the ways in which those activities fulfill MDT's programmatic goals. Depending on the activity class, the introduction may provide high-level guidance on planning work activities. Some chapters lack this information. For example, the chapters on asphalt pavement and concrete pavement preservation instead provide an overview of pavement deficiencies and their causes. Including this knowledge is useful for designing and implementing a long-term pavement maintenance program. Pavement chapters also integrate brief narratives on different types of deficiencies (e.g., rutting, raveling, cracking, potholes), specify their underlying causes, comment on methods to inspect and measure the severity of the deficiency (if available), and present corrective measures. Chapter introductions also discuss whether permits or approvals are generally needed to conduct specific tasks and direct supervisors and workers to the appropriate Montana state government agency to obtain the requisite permits. Permits are not generally necessary for maintenance activities, though may be required for some (such as cleaning culverts, culvert replacement) which result in discharges to adjacent bodies of water covered by Section 404 of the Clean Water Act or state environmental regulations. Other issues addressed in some chapter, but not all, introductions are safety and training — for those activities that may prove hazardous, — environmental best management practices, and necessary documentation. Like many other states, Montana uses a Maintenance Management System (MMS) to record maintenance activities. It keeps track of labor, materials, equipment, and the activity cost according to route and location. Any documentation required for a maintenance activity is entered into the MMS according to the *Maintenance Management System Manual of Instructions*. Following chapter introductions, activity standards are laid out sequentially for each activity within the activity class.

Each activity standard begins with a description of the activity, focused principally on what the activity is designed to accomplish. For example, the activity description that accompanies Activity 5.1, *Cleaning Culverts, Culvert Opening, and Basin Inlets*, states that its goal is to remove obstructions from culvert ends as well as silt from inlets and catch basins. It then specifies other elements which are targeted (e.g., culvert catch basins). Following the activity description is a statement of purpose, which highlights the intended outcome of the activity. For example, removing dirt and excess vegetation from culverts helps improve water flow and drainage, which can have implications for maintaining ecologically suitable habitat. Purpose statements also mention, in some cases, what benefits accrue to the roadway system — and its condition — by performing an activity. Next, the standard defines the timing of maintenance. There is considerable variability in the specificity of timing statements. For many activities, the manual does not contain a set timetable for conducting inspections and performing regularly scheduled maintenance, or it directs personnel to execute an activity on an as-needed basis. Examples of activities without timetables for inspection and maintenance include surface patching of potholes (which should be repaired as quickly as possible once they appear), guardrail repair or replacement, and pavement striping and markings (both should be rejuvenated once their retro-reflectivity and visibility declines). Other activity standards lay out definite inspection and maintenance timelines. For example, chip sealing is to be done every five to seven years — contingent on pavement condition — or following the placement of a new overlay. Culverts, culvert openings, and basin inlets are inspected twice a year and following major storms to determine whether they require cleaning or structural repairs. A number of activity standards contain more ambiguous language regarding inspection, holding they should be done *routinely* or *regularly* or *periodically*, without specifying the timeframe associated with these descriptors. Following guidelines on timing, activity standards list any specialized equipment and materials needed to complete a maintenance task. Notes on special safety or training provisions follow and, if warranted, environmental best management practices. The final section in each activity standard is a condensed description of the procedure used to carry out the maintenance activity — notes on procedures cover everything from pre-planning and coordinating with other staff beforehand to instructions for onsite performance of the activity. In some cases, maintenance staff are directed to consult supplementary guidance, manuals, and handbooks, those issued by MDT as well as other state of Montana government agencies, for more comprehensive instructions. Table 2 summarizes key maintenance activities, including an explanation of the activities and timing requirements outlined in MDT's maintenance manual. The table is not exhaustive and omits activities that do not align with those which are part the aspects of KYTC's core maintenance program being investigated by this study. Language reproduced in the table with respect to timing (words such as *promptly*, *routinely*, *periodically*) are taken verbatim from the manual. This information should give readers a better sense of which maintenance activities are placed on definite schedules and which are done regularly but lack explicit protocols.

Table 2: Key Montana DOT Maintenance Activities

Maintenance Category	Maintenance Activity	Activity Explanation	Timing, Scheduling, and Other Comments
Asphalt Pavement Program	Surface Patching — Hand	• Hand fill potholes	• No set time table or inspection schedule • Promptly repair potholes • Post warning signs near potholes if weather or other factors prevent immediate repair
	Crack Sealing/Joint Filing	• Route, clean, and seal/fill cracks	• Examine overlays and new pavement surfaces for crack sealing every third year after a project has been completed • Use MDT's Pavement Management System and visual analysis to determine if crack sealing is needed
	Chip Sealing	• Controlled application of liquid asphalt and aggregate cover to a highway surface	• Every 5-7 years, based upon pavement condition, or after a new overlay
	Rejuvenating/Fog Seal	• Apply an emulsion or liquid asphalt to a roadway surface at a prescribed rate	• Use following blade patches or chip seals • As a standalone treatment, use on an as-needed basis
Concrete Pavement Program	Temporary Patching of Portland Cement Concrete Pavement	• Patch broken or spalled areas	• No set time table or inspection schedule • Begin patching as soon as practicable after potholes form

	Permanent Patching of Portland Cement Concrete Pavement	• Use permanent patch materials (e.g., high, early-strength Portland Concrete Cement) to patch broken or spalled areas	• Install permanent patches when: ○ Weather conditions support the proper curing of materials ○ Vehicle flow can be restored before peak times on busy routes ○ Traffic control can be established to allow for patching several areas in one control zone
	Crack and Joint Sealing	• Prepare and seal joints and cracks in concrete pavement • Prepare and seal the longitudinal joints between concrete pavement and asphalt	• No set time table or inspection schedule • Repair cracks when they are at their widest due to the contraction of concrete and asphalt
Roadway/Roadside Maintenance	Cleaning Culverts, Culvert Openings, and Basin Inlets	• Remove obstructions from culvert ends and eliminate silt from inlets and catch basins	• Inspect facilities twice each year and following major storms to establish whether cleaning or structural repairs are necessary

	Culvert Repair, Replacement, and Fish Betterment	• Repair and replace structurally deficient culverts • Repair and replace catch basins, drop inlets, manholes, culverts, erosion control features, fish baffles and weirs, retaining walls, and defects at pump stations	• Inspect facilities twice each year • Repair facilities and structures when they no longer function as designed
	Cleaning, Shaping, and Repairing Ditches	• Clean and shape roadside ditches (includes hauling and disposal of excess material, restoring proper grade line and side slope configuration to preserve adequate drainage)	• Periodically inspect ditches to evaluate their condition • Inspect ditches after major storms to determine if cleaning and shaping is necessary
	Slope Repair	• Repair slopes that have eroded or suffered flood damage	• Conduct periodic inspections to resolve whether repairs are necessary • Repair slopes before they become safety hazards or undermine the structural integrity of the road • Perform work during water-work periods

	Unpaved Road Surface	• Blade unpaved surfaces and shoulders with a motor patrol	• Routinely inspect gravel surfaces • Make repairs before drivability and integrity of the roadway surface are impacted • Execute repairs when surface moisture is present to ensure it is properly compacted
	Vegetation Management — Mechanical Mowing	• Mow roadside vegetation	• No set time table or inspection schedule • Mow when necessary, as part of a road management plan • Limit mowing to the growing season if possible • If possible, schedule mowing to support noxious weed control planning and forage removal/haying operations
	Chemical Vegetation Control — Chemical Spraying	• Use of chemical to limit the growth and spread of noxious weeds • Slow the growth of vegetation around structures (e.g., signs and guardrails), improve aesthetics, and enhance sight distance	• Chemical applications are typically made in fall or spring according to manufacturer directions

	Vegetation Management — Brush and Tree Removal	• Remove unwanted brush, trees, and vegetation from the right of way and adjacent to signposts, guardrails, or other structures	• Remove unwanted vegetation when it begins to reduce sight distance, sign visibility, or becomes a nuisance or fire hazard
	Maintenance of Landscaped Areas	• Mowing, maintenance of water systems, fertilizing, weeding, and replacing turn in landscaped areas	• Mow when as needed to maintain aesthetics • Prune trees and shrubs when they are dormant • Frequently edge walks, curbs, and highly visible elements • Winterize irrigation at the end of the growing season
	Inspection and Repair of Fences and Gates	• Maintain or replace fence posts, top rails, and gates of MDT-owned fences	• Inspect fences twice per year and schedule repairs and maintenance accordingly
	Cattle Guard Repair	• Repair and install cattle guards and related structures and fence connections	• Periodically inspect and clean cattle guards • Immediately repair damage to cattle guards
Roadside Cleanup Program	Removal of Debris and Litter	• Remove litter, debris, and trash from the right of way	• Conduct routine patrols periodically to remove roadway debris • Frequency of cleanup is a product the amount of litter, debris, and hazardous items that have accumulated and whether unsightly, unsanitary conditions result

	Sweeping or Flushing	• Remove gravel, dirt, and sand from intersections, bridges, travel ways, shoulders, and paved ditches by sweeping them or flushing them with water	• No set inspection schedule • Remove dirt, sand, or other debris that pose a hazard as soon as practical • Dirt, sand, or small debris collected in curbs, gutters, and drainage outlets should be removed as soon as practical to avoid sedimentation • Sweep excess deicing materials from the roadway as soon as practical
Maintenance of Facilities	Maintenance of Rest Areas	• Maintain and repair rest areas and truck parking areas	• Inspect rest areas at least once per week, but preferably daily • Perform necessary repairs as soon as practical to keep facilities operational
Guidance, Safety Devices, and Road Closures	Traffic Signs	• Encompasses: • Repair, maintenance, and replacement of traffic signs, posts, and sign panels Cleaning, tightening bolts, straightening signage Maintaining single post, double posts, overhead sign faces, hazard markers, chevrons, and reference markers	• No set time table or inspection schedule • Promptly repair and replace signs critical to traffic safety • Install a temporary sign if a quick and permanent fix is not possible

	Guardrail Repair and Replacement	• Maintenance of guardrails, including: • Repairing or replacing damaged or deteriorating panels • Replacing damaged posts • Straightening or aligning posts and panels • Replacing cables and posts • Removing and replacing concrete barriers • Performing routine inspections to ensure cables are properly tensioned, appropriate torque on bolts	• No set time table or inspection schedule • Repair damage to guardrails as quickly as possible
	Pavement Striping	• Place solid and skip pavement markings on pavement surfaces • Apply glass beads to lines after painting	• No set inspection schedule • Renew pavement stripes after they have lost retro-reflectivity or line integrity • Complete 85 percent of restriping activities by July 1
	Pavement Markings	• Place markings, legends, and symbols on the pavement surface (e.g., crosswalks,	• No set time table or inspection schedule • Renew pavement stripes when visibility or retro-reflectivity diminishes

		stop bars, directional arrows, word messages)	
	Maintenance of Delineators, Reference Markers, and Snow Poles	• Replace bent, broken, or missing delineators, milepost markers, and snow poles	• No set time table or inspection schedule • Repair missing or damaged delineators as soon as practical • Clean delineators as needed to maintain retro-reflectivity • Conduct periodic inspections to identify damaged or missing mileposts and delineators • Install snow poles before the onset of the winter season
	Flashing Lights, Traffic Signals, and Luminaries	• Inspect, repair, and do preventive maintenance on flashing lights, traffic signals, and luminaries	• Perform routine inspections to ensure all signals, lights, and flashers work properly • Inspect luminaries at night to identify malfunctions
	Impact Attenuators (Crash Barriers), Repair to Escape Ramps	• Repair or replace deteriorated and damaged attenuators	• Perform routine inspections of impact attenuators and escape ramps to ensure their proper function • Correct deficiencies that impair the functional integrity of attenuators immediately

Structure Maintenance Program	Maintenance and Repair of Structures	• Repair damage or deterioration of bridge components • Remove debris and drift near piers • Clean drains, decks, joins, or bearings • Clean and paint timber bridge rails • Tighten or replace bolts and nuts • Repair or replace joint materials and joint headers • Repair or replace bridge rail, curb, or posts • Adjust bridge height following settlement • Repair and replace timber girders, caps, decks, and piles • Repair vehicle impact damage to beams and columns	• Timing varies among activities — • Clean deck drains when temperatures are above 32 degrees • Clean bridge decks in the spring • Patch or repair concrete when weather permits • Remove debris and drift material around piers as soon as practical • Correct structural deficiencies as soon as practical
	Inspection of Structures: Bridges and Culverts	• Inspect bridges in accordance with National Bridge Inspection Standards • Inspect culverts, box culverts, and comparable drainage structures	• Inspect all culverts and bridges occur every six months • Inspect bridges and culverts after they are impacted by a major event (e.g., earthquake, flood, high water runoff)

Alabama

The Alabama Department of Transportation (ALDOT) maintains approximately 12,000 roadway miles. Specifically, the agency's Maintenance Bureau is responsible for overseeing and conducting maintenance activities. With respect to maintenance, there are four levels of management: top management, bureau of maintenance management, division of maintenance management, and district maintenance management. Each year, annual maintenance programs are developed that describe the type and amount of maintenance work to be performed during the upcoming fiscal year. Annual maintenance programs specify the labor, equipment, and materials necessary to execute planned maintenance work, while annual maintenance budgets include allotments for routine maintenance (which includes emergency work), maintenance resurfacing, and minor maintenance betterments. Each division and district receives an individualized maintenance program that has been customized based on existing maintenance standards and current roadway inventory data. Once the annual maintenance program has been developed and approved, the Maintenance Bureau distributes the work program to personnel responsible for scheduling, supervising, performing, and controlling maintenance work. The Division Maintenance Engineer, District Engineer, and Superintendent are responsible for scheduling and performing authorized work. Superintendents in district offices are responsible for performing routine inspections to determine what maintenance activities are required; coordinate and schedule maintenance work with the District Engineer; assign labor, equipment, and materials for maintenance work.

ALDOT has several publications related to the maintenance program, including a *Field Operations Manual* (ALDOT, undated), its *Level of Service Condition Assessment Data Collection Manual* (ALDOT 2015), and a compendium of maintenance performance guidelines (ALDOT 2014). The *Field Operations Manual* is a broad overview of the agency's maintenance program; reviews the delegation of responsibility amongst personnel; contains a detailed activity list that provides abridged narratives of work activities and identifies work measurement units; instructions for scheduling work crews; guidelines for evaluating work performance; and various templates of forms used by Maintenance Bureau personnel (e.g., maintenance activity summary worksheets, crew day cards). The manual also lists maintenance work control categories, which for each maintenance activity specifies the work control category it falls under, scheduling responsibilities, and the type of crew required.

ALDOT has four categories of maintenance tasks: routine unlimited activities, routine limited activities, special authority activities, and overhead activities. Routine unlimited activities encompass high-priority assignments that are completed on an as-needed basis to minimize roadway deficiencies. Activities falling under this designation include spot premix patching, snow and ice removal, and emergency maintenance. Routine limited activities are those for which quantities of work are prescribed and firmly adhered to. Examples include mowing — done a fixed number of times each year — and bridge inspections, which are undertaken every two years. Next, special authority activities are non-critical tasks which need not be completed within a given year. Some of the activities included under this heading are erosion control, shovel ditching, brush and tree cutting, and special maintenance activities (e.g., major bridge repair, minor maintenance improvements). Overhead activities consist of tasks that are unrelated to the maintenance of a specific roadway or structure, such as weighing operations, training, or materials handling. Personnel in Division and District offices have distinct responsibilities for scheduling maintenance tasks. Division-wide specialized activities that require division-wide crews (e.g., centerline painting, major bridge repair, minor maintenance improvements) are scheduled by the Division Maintenance Engineer. It is the responsibility of the District Engineer to program some special authority work and specialized work, such as major premix patching and sign maintenance. Superintendents make decisions about scheduling day-to-day maintenance work; inspection activities must be performed regularly to identify locations where routine maintenance is necessary.

Table 3: Metrics Used by the Alabama DOT to Evaluate the Condition of Maintenance Features

Asset Classification	Maintenance Feature	Maintenance Feature Condition Measure
Asphalt Pavement	Potholes (≥ 6"x6"x1")	Number of potholes per lane mile
	Raveling	% of surface area distressed
	Shoving (Upheaval/Depression)	Square feet of deficiencies per lane mile
Concrete Pavement	Spalling (≥ 6"x 6"x1")	Number of spalls per lane mile
	Faulting (≥ 1/4" high)	Number of faulted slaps per lane mile
	Joint Sealing (≥ 1/4" wide)	Linear feet of joints requiring sealing per lane mile
	Pumping	Number of slabs deficient per lane mile
	Punchouts (≥ 6"x6" surface area with full depth failure)	Number of punchouts per lane mile
Shoulders	Potholes (≥ 6"x6"x1")	Number of potholes per lane mile
	Edge Raveling (Edge Failure)	Linear feet per shoulder mile
	Sweeping	Linear feet of paved shoulder needing sweeping
	Non-Paved — Drop Off (≥ 2") (Low Shoulder)	Linear feet per shoulder mile
	Non-Paved — High Shoulder > 1" (Built-Up Shoulder)	Linear feet per shoulder mile
Drainage	Side Drains	% of pipes not functioning as intended of > 25% blocked
	Cross Drains	% of pipes not functioning as intended or > 10% blocked
	Unpaved Ditches	% of ditch length not functioning as intended (erosion or blockage)
	Paved Ditches	% of ditch length not functioning as intended or blocked
	Drop Inlets, Slotted Drains, and Catch Basins	% of inlets not functioning as intended or blocked
	Curb and Gutters	% of length not functioning as intended or misaligned
Roadside	Front Slope — Erosion Control	% of shoulder miles deficient — washouts > 12"
	Back Slope — Erosion Control	% of shoulder miles deficient — washouts > 18"
	Mowable Area	Average height of grass (in inches)

	Brush Control (blocking line of sight or signage or within the "clear zone")	% of shoulder miles with desirable brush
	Tree Removal	Number per shoulder mile
	ALDOT Fence	% of fence miles damaged (functionally deficient — requiring repair)
	Litter Control	Number of equal to or greater than fist-sized objects per shoulder mile
Traffic Services	Raised Pavement Markers	% of RPMs missing or damaged per center line mile
	Signals (e.g., bulbs malfunctioning, structurally deficient, facing wrong direction)	% of signals deficient
	Delineators	% of delineators deficient
	Object Markers	% of makers missing or damaged
	Signs — Warning and Regulatory (damaged, missing, illegible, retro-reflectivity)	% of signs deficient
	Pavement Striping (non-visible, missing, faded, chipped)	% of total length deficient
	Guardrail	% of guardrail length deficient
	Cable Rail	% of cable rail length deficient
	Impact Attenuators	% of impact attenuators needing repair
	Barrier Walls	% of barrier length deficient
	Highway Lighting (low or high mast)	% malfunctioning (LOS Condition only, no budgeting initially)
	Pavement Markings and Legends (non-visible, missing, faded, chipped)	% of symbols and legends deficient

ALDOT's *Level of Service Condition Assessment Data Collection Manual* states that data on the condition of infrastructure assets is used to "develop customer-oriented, performance-based work plans and budgets and to assess results." As such, these data inform the development of the agency's Maintenance Management System. The manual contains procedures work crews should follow when collecting and processing road inventory data. Its first section focuses primarily on data collection guidelines, equipment required for gathering data in the field, and safety protocols; it also includes an overview of maintenance condition assessment criteria. Where possible, agency personnel are instructed to gather inventory data and condition data from existing sources (e.g., office records, application databases, mainframe feature inventory). Information not found in these sources is collected in the field, ideally using three-person crews, which maximizes the efficiency of inspection work and enhances crew safety. Field data collection does not occur along every mile of roadway. Rather, each district randomly samples 0.1-mile road segments to assess their condition — the number of segments varies among districts and is determined by the total number of roadway miles in the district. For most districts, between 200 and 350 road segments must be appraised to obtain a statistically representative sample of roadway conditions. ALDOT recommends collecting data over the shortest possible time span to ensure an accurate representation of road conditions, as this informs planning and budgeting. Following the introductory material, the manual provides a detailed review of data collection criteria for each maintenance feature. There are individual entries for each feature that requires inspection. Entries list the asset group and maintenance feature, specify what constitutes a deficient condition, states measurement units, and describes the inspection procedures. Most entries also incorporate one or several images, which serve as a visual reference point to help field crews accurately evaluate roadway conditions and identify problem areas. Table 3 summarizes asset classifications, maintenance features, and the criteria used to determine asset condition. The manual does not include discussions of how inventory condition data are used to set maintenance priorities.

The final published maintenance resource is ALDOT's catalogue of maintenance performance guidelines. Like other states, there are entries for each maintenance activity that include a description and purpose of the task; information on authorization and scheduling; and notes on the required crew size, equipment and material needs, how to perform the maintenance task, and average daily production. Many of the entries' sections on authorization and scheduling lack precise timelines specifying when and how often maintenance tasks are to be carried out. Scheduling guidelines tend to be very broad. For instance, activities such as Other Roadway and Shoulder Maintenance (which includes tasks such as sweeping, base repair, spot patching, and cleaning curbs and gutters) and Drainage Maintenance are to be scheduled throughout the year. Some activities include definite timelines. For example, Line Trimming should begin in the late spring. To familiarize readers with which activities occur at defined intervals or specific points during the year (and which are done on a more as-needed basis), Table 4 lists maintenance activities and the scheduling information provided in the agency's maintenance performance guidelines.

Table 4: Alabama DOT Scheduling Guidelines for Maintenance Activities

Maintenance Activity	Scheduling Guidelines
Condition Assessments	• Schedule at discretion of the Maintenance Bureau
Spot Premix Patching (Hand Operation)	• Schedule as soon as practical following discovery
Major Premix Patching (Machine Operation)	• Coordinate scheduling with division-wide resurfacing operations
Skin Patching	• No timeline specified
Strip Patching	• Coordinate scheduling with division-wide resurfacing operations
Crack Sealing Concrete Pavement	• Schedule after field inspections find existing crack sealers are no longer effective or random cracking has developed that could let water damage the base material

Crack Sealing — Asphalt Pavement	• Schedule after field inspections find existing crack sealers are no longer effective or random cracking has developed that could let water damage the base material
Pavement Planning	• Schedule as soon as practical once pavement defects or irregularities are found
Patching Unpaved Shoulders	• Schedule as needed
Blading Unpaved Shoulders	• Schedule work to take advantage of natural moisture (typically fall or spring)
Cleaning Concrete Joints	• Schedule once field inspections find existing joint sealers are no longer effective
Joint Sealing	• Division Maintenance Engineer authorizes and schedules work once field inspections indicate existing joint sealers are ineffective
Concrete Pavement Repair	• Schedule as needed throughout the year
Other Roadway and Shoulder Maintenance	• Schedule as needed throughout the year
Ditching	• Schedule, if possible, in early summer once ditches have dried so grasses can establish before winter
Cleaning Minor Drainage Structures	• Inspect all minor drainage structures at least once per year Cleaning is scheduled in the spring or fall and sometimes following heavy rainfall
Repairing Minor Drainage Structures	• Schedule as needed throughout the year (preferably during slack periods)
Other Drainage Maintenance	• Schedule as needed throughout the year
Impact Attenuator Maintenance	• Schedule as needed throughout the year
Concrete Barrier Rail Maintenance	• Schedule as needed throughout the year
Mowing (Interstate)	• Schedule to begin in late spring before tall grasses reach maturity, but after clovers reach maturity
Mowing (Non-Interstate)	• Schedule to begin in late spring before tall grasses reach maturity, but after clovers reach maturity

Boom Mowing	• Schedule to begin in late spring before tall grasses reach maturity, but after clovers reach maturity
Line Trimming	• Schedule to begin in late spring before tall grasses reach maturity, but after clovers reach maturity
Herbicide Treatments	• Schedule as needed throughout the year
Herbicide Treatment Surveillance	• Schedule at least 10 days after the initial herbicide treatment
Brush and Tree Cutting	• Schedule when brush or tree growth may interfere with sight distance, traffic signs or signals, or impairs aesthetics
Erosion Control	• Schedule as needed throughout the year
Litter Pickup (Full Width)	• Schedule work before the start of the mowing season and after the mowing season Some areas require attention throughout the year
Litter Pickup (Spot)	• Schedule work before the start of the mowing season and after the mowing season Some areas require attention throughout the year
Spot Herbicide Treatment	• Schedule work in the spring when temperatures are warm enough for treatment to be effective Reschedule as needed throughout the year
Landscape Enhancement Projects	• Schedule at discretion of the Maintenance Bureau
Wildflowers Projects	• Schedule at discretion of the Maintenance Bureau
Other Roadside Maintenance	• Schedule as needed throughout the year
Sign Installation, Replacement, or Removal	• Schedule as needed throughout the year to ensure all sign installations conform with the MUTCD
Sigh Maintenance	• Schedule as needed throughout the year
Centerline and Edge Painting	• Coordinate scheduling with resurfacing activities

Pavement Markings and Legends	Schedule as needed throughout the year Emphasize crosswalks prior to the school year beginning
Guardrail Maintenance	Schedule as needed throughout the year
Cable Rail Maintenance	Schedule as needed throughout the year
Traffic Signal Maintenance	Schedule as needed throughout the year
Raised Pavement Marker Maintenance	Coordinate scheduling with resurfacing activities
Other Traffic Operations	Schedule as needed throughout the year
Roadside Improvements	Division Maintenance Engineer authorizes and schedules work throughout the year as needed
Drainage Improvements	Division Maintenance Engineer authorizes and schedules work throughout the year as needed
Traffic Operations Improvements	Division Maintenance Engineer authorizes and schedules work throughout the year as needed

Florida

The Florida Department of Transportation's (FDOT) Office of Maintenance is responsible for maintaining the state's infrastructure assets. Several published resources are available from the agency detailing various aspects of its maintenance program, including the *Maintenance Rating Program Handbook*, *Bridge Maintenance and Repair Handbook*, *Guide for Roadside Vegetation Management*, and several others related to FDOT procedures. At FDOT, maintenance engineers recommend levels of service for highway elements (the targeted condition for assets), while field supervisors adopt these suggestions to inform inspection and maintenance activities. Field supervisors are responsible, as well, for judging which roadway elements are to be maintained at the targeted level of service and which can be allowed to fall below that condition. To establish maintenance standards and inspections procedures that would be applied consistently throughout Florida, in 1985 the agency introduced its Maintenance Rating Program (MRP). Individual districts administer the MRP. Our focus here is on FDOT's *Maintenance Rating Program Handbook* (FDOT 2017; hereafter referred to as *handbook*), as it offers the most insights how the agency approaches rating asset conditions and maintenance.

In addition to discussing the broad contours of FDOT's maintenance program, the handbook outlines methods for conducting visual and mechanical evaluations of routine highway maintenance conditions. It does not apply to bridges, as they are covered by a separate program. Data collected from inspections are used to plan and prioritize routine maintenance activities and ensure maintenance programs are being designed and implemented consistently around Florida. During each reporting period (of which there are three per year), the Office of Maintenance uses a random sampling methodology to specify which facilities will be inspected. There are three reporting periods throughout the fiscal year. After the facilities are chosen, they are evaluated by an inspection team consisting of two people, one of whom is qualified as a team leader. Inspection teams examine 30 points per facility type or cost center, or a minimum of three points per mile for facility types that are less than 10 miles long. Each sample is 1/10 mile (528 feet). The handbook provides instructions on collecting data, lists the equipment and supplies needed to conduct facility inspections, and includes coding sheets that are used to record survey data in the field. Individual entries in the handbook offer detailed guidance on inspecting facilities (see below). FDOT classifies facilities into four groups based on the type of maintenance applied to them: 1) rural limited access, 2) rural arterial, 3) urban limited access, and 4) urban arterial. Each facility is then partitioned into five elements — roadway, roadside, traffic services, drainage, and vegetation and aesthetics. Each element has several characteristics that are inspected. Taken together, the characteristics make up the maintenance element. For instance, the following attributes comprise the roadway element — unpaved shoulder, front slope, slope pavement, sidewalk, and fence. The handbook states that six characteristics are evaluated on all samples: 1) potholes, 2) depressions, 3) raised pavement markers, 4) striping, 5) tree trimming, and 6) litter removal. On rigid roadways, joints and cracking are evaluated for all facility types, while for flexible roadways all samples are inspected for edge raveling and shoving. Once inspection teams collect data they enter them into FDOT's data processing system, after which they are used to inform decision making about maintenance. The handbook and processes described therein are regularly reviewed by staff from around the state to determine whether revisions are necessary. The agency performs quality assurance reviews annually for each MRP team leader. A quality assurance team scrutinizes the quality of their work (to ensure their assessments are consistent) and adherence to the agency's safety protocols.

The second portion of the handbook is comprised of a catalogue of detailed entries that provide an overview of how different characteristics are to be evaluated and rated. Entries list the target condition for each characteristic as well as a description of the feature; a detailed, step-by-step inspection procedure; supplemental notes if necessary, a list of conditions which, if present, would cause the characteristic to not meet MRP standards; and ample photographic examples inspectors can use in the field to guide their assessments. Table 5 lists, for each roadway element and its associated characteristics, targeted maintenance conditions. Assets failing to meet these threshold conditions warrant maintenance attention. While the handbook does not list intervals for conducting routine maintenance activities, readers may be able to approximately infer their frequency based on the inspection schedule and targeted maintenance condition.

Table 5: Target Maintenance Condition for Florida DOT Infrastructure Characteristics

Element	Characteristic	Target Maintenance Condition
Roadway	Flexible Pothole	• No defect with an area greater than 0.5 square feet and no individual measurement greater than 1.5" deep • No exposure of the pervious base
	Flexible Edge Paving	• 90% of total roadway edge free of raveling No continuous section of edge raveling greater than or equal to 4" is more than 25 feet long
	Flexible Shoving	• Cumulative shoved area is not greater than 25 square feet
	Flexible Depression/Bump	• No deviation greater than 0.5" for any area greater than 1 square foot • No one measure should exceed 2"
	Flexible Paved Shoulder/Turnout	• Paved shoulders are to be rated for potholes, edge raveling, depressions, and bumps • Rate flexible turnouts for only potholes

	Rigid Pothole	• No defect with an area greater than 0.5 square feet and no individual measurement greater than 1.5" deep • No exposure of the pervious base
	Rigid Depression/Bump	• No deviation greater than 0.5" for any area greater than 1 square foot • No one measure should exceed 2"
	Rigid Joint/Cracking	• 85% of the length of transverse longitudinal joint material functions as intended, **or** • 90% of roadway slabs have no sealed cracks wider than 1/8"
	Rigid Paved Shoulder/Turnout	• Rigid paved shoulders are to be rated for potholes, depressions, bumps, joints, and cracking • Rigid turnouts are only rated for potholes and cracking
Roadside	Unpaved Shoulder	• No deviations across the shoulder wider than 5" above or below the design template • No shoulder build-ups greater than 2" anywhere across the design template for 25 continuous feet • No shoulder drop-offs more than 3" deep within 1 foot of the pavement edge for 25 continuous feet • Sand, soil, grasses, or debris are not to encroach 12" or more on the outside the paved shoulder for 25 continuous feet • No washboard areas with a total differential greater than 5" from the low spot to high spot
	Front Slope	• No depth or height deviations greater than 6"
	Slope Pavement	• No individual areas of missing, settled, or misaligned areas greater than 10 square feet
	Sidewalk	• 99.5% of sidewalk area does not have vertical misalignments greater than 0.25" or horizontal cracks greater that 0.5" • No visible hazards
	Fence	• No unrestrained free entry is allowed
Traffic Services	Raised Pavement Markers	• 70% of required markers are functional (reflective) No locations where there is more than 100 continuous feet of centerline or lane line without a reflective marker

	Striping	• 90% of the length and width of each lane line functions as intended
	Pavement Symbols	• 90% of existing symbols function as intended
	Guardrail	• Each single run functions as intended
	Signs Less Than or Equal to 30 Square Feet	• 95% of signs function as intended
	Signs Greater Than 20 Square Feet	• 85% of signs function as intended
	Object Markers and Delineators	• 80% of markers function as intended
	Lighting	• 90% of all luminaries of combined sign and highway lighting function as intended
Drainage	Side/Cross Drain	• 60% of each pipe's cross section contains no obstructions and functions as intended
	Roadside/Median Ditch	• Ditch bottom elevation cannot vary from the design elevation by more than 1/4 of the difference between the edge of pavement elevation and the ditch's design elevation
	Outfall Ditch	• Ditch bottom elevation cannot vary from the design elevation more than 1/3 of the difference between the natural ground and design flow line
	Inlets	• 85% of the opening is unobstructed
	Miscellaneous Drainage Structure	• 90% of each structure functions as intended
	Roadway Sweeping	• Material accumulation does not exceed 0.75" for more than 1 continuous foot in the traveled way, **or** • Material accumulation does not exceed 1.5" for more than 1 continuous foot in any gutter
Vegetation and Aesthetics	Roadside Mowing	• No more than 1% of mowing exceeds the specified height guidelines (including seed stalks and decorative flowers): ○ Rural Limited Access — 5"-18" ○ Rural Arterial — 5"-12" ○ Urban Limited Access — 5"-12" ○ Urban Arterial — 9" maximum

	Slope Mowing	• No more than 2% of vegetation is higher than 24" (excluding seed stalks and decorative flowers) Evaluate using standards in *A Guide for Roadside Vegetation Maintenance*
	Landscaping	• 90% of landscape vegetation is in a healthy, attractive condition
	Tree Trimming	• No trees, tree limbs, or vegetation should encroach upon the travel way or clear zone lower than 14.5 feed, or below 8.5 feet for sidewalks, curbs, and gutter clear zones
	Curb/Sidewalk Edge	• No vegetation or debris encroachment onto the curb or sidewalk for more than 6" for more than 10 continuous feet • Soil height cannot deviate more than 4" above or 2" below the top of the curb or sidewalk for more than 10 continuous feet
	Litter Removal	• Litter volume is not greater than 3 cubic feet per acre, excluding all travel way pavement • No unauthorized graffiti or stickers within the state's right of way on state-owned property • No litter hazards on the roadway, paved shoulder, or clear recovery zone
	Turf Condition	• Turf in mowing area is 75% free of unwanted vegetation • No wanted vegetation growing out of Mechanically Stabilized Earth and Sound Wall greater than 6" in length • No more than 7.5 square feet of unwanted vegetation in any 50 square foot area of paved shoulder, pavement joints, concrete traffic separators, curb/asphalt joints, and under guardrail • No vegetation damaging or displacing the asset structure

Key Takeaways

- Predictably, the organization and implementation of maintenance programs vary among state agencies with respect to scheduling and executing work.
- Many agencies have specified target maintenance conditions, which specify a desired level of service and define what conditions should be present at a facility to achieve performance goals.
- Inspection programs are integral to setting maintenance priorities. Many states inspect a random sample of facilities two or three times per year to identify what maintenance is needed. MDT, for example, inspects some facilities, such as ditches and drainage outlets, following extreme weather events (e.g., flooding) that can impact their performance. Some maintenance activities are performed at regular

intervals, but many are done on an as-needed basis pursuant to the findings of inspections or when a problem first arises.

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