



# PERFORMANCE-BASED PLANNING AND PROGRAMMING FOR PAVEMENT MANAGEMENT

June 2016

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**Performance-based Planning and Programming for Pavement Management**

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**Task A.7. ITS/CAV Data Support of Asset Management**

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## EXECUTIVE SUMMARY

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Transportation agencies are frequently challenged by budget constraints to maintain roadway pavements and other infrastructure in good condition. As a result, it is critical that transportation infrastructure investments are cost-effective and results-oriented. *Performance-based Planning and Programming* (PBPP) is the application of performance management principles within the planning and programming processes of transportation agencies to achieve desired performance outcomes for a multimodal transportation system. *Transportation Asset Management* (TAM) is strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively through their life cycle, and is ideally adopted within a broad PBPP framework. For many, if not all, transportation agencies, highway pavements are the most valuable asset that they manage. Thus, performance (life-cycle) management of pavements is a critical component of a TAM system.

Within pavement performance management, four primary metrics of pavement condition are used: *structural-adequacy/deflection*, *surface distress*, *serviceability* (smoothness), and *surface friction*. The most commonly collected of these primary metrics are those that are required for federal reporting. Under the National Highway Performance Program (NHPP) introduced in the 2012 federal transportation funding bill (MAP-21) and adopted by the 2015 FAST Act, states are required to report surface distress metrics of cracking, rutting, and faulting, as well as serviceability (in the form of the International Roughness Index [IRI]). Dozens of other primary and secondary metrics also can provide additional value.

The Michigan Department of Transportation (MDOT) has historically operated a pavement management system based on a department-created ‘distress index’ (DI), which is then used to estimate the pavement’s remaining service life (RSL). MDOT also uses a pavement rating scale (PASER) via ‘windshield survey’ to assess road conditions for the entire statewide system.

Under emerging federal regulations, MDOT will be required to adopt specific PBPP practices including the development and use of a risk-based Transportation Asset Management Plan (TAMP) for the statewide National Highway System (NHS). The TAMP will be required to address metrics and targets established by the NHPP, and thus will require MDOT to amend established TAM practices.

Federal NHPP requirements set minimum standards for pavement performance management, but states are encouraged to incorporate additional metrics on pavement and other infrastructure assets in the state TAMP. Advancing technologies may allow for the creation of novel metrics and collection techniques that could expand the scope of Michigan's TAMP and facilitate more cost-efficient outcomes in all aspects of TAM. Technology advances that could be integrated into a TAM program include:

- Smartphone apps and crowdsourcing
- Automated vehicle systems data
- In situ structural health monitoring
- Automated distress classification

Regardless of what data are collected, a transportation asset management program must be appropriately designed to be capable of translating raw data into useful, actionable information. Currently, the state-of-the-practice in pavement design and performance management is a mechanistic-empirical (M-E) approach favored by the American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Administration (FHWA). AASHTO published the *Mechanistic-Empirical Pavement Design Guide* (MEPDG) in 2008 with associated design software. MDOT adopted the MEPDG for pavement design in 2015. Fully utilizing improved pavement design approaches and novel data types will require expanding the use of coherent PBPP frameworks across the organization.

Further information regarding performance-based transportation asset management and pavement performance management is available from the FHWA Asset Management Program Office at <http://www.fhwa.dot.gov/asset/>, and the AASHTO TAM Portal at <http://www.tam-portal.com/>.

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# 1 INTRODUCTION

Pavements and bridges are typically the most critical infrastructure assets managed by transportation agencies. Measuring and forecasting the condition of pavements is a central process in any transportation agency’s overall asset management program. Many state departments of transportation and Metropolitan Planning Agencies (MPOs) have adopted transportation asset management (TAM) processes to promote effective use of department resources. However, many TAM programs are structured such that it is difficult to determine how effective investment strategies are at achieving department performance goals.

With the passage of the MAP-21<sup>1</sup> federal transportation funding bill—and subsequent FAST Act—the Federal Highway Administration (FHWA) will be responsible to ensure that states and MPOs implement TAM processes that are adequately performance-based. Pavement performance management is a significant aspect of TAM, but TAM typically includes more assets than pavements. This chapter provides background information on recent federal requirements and required concepts.

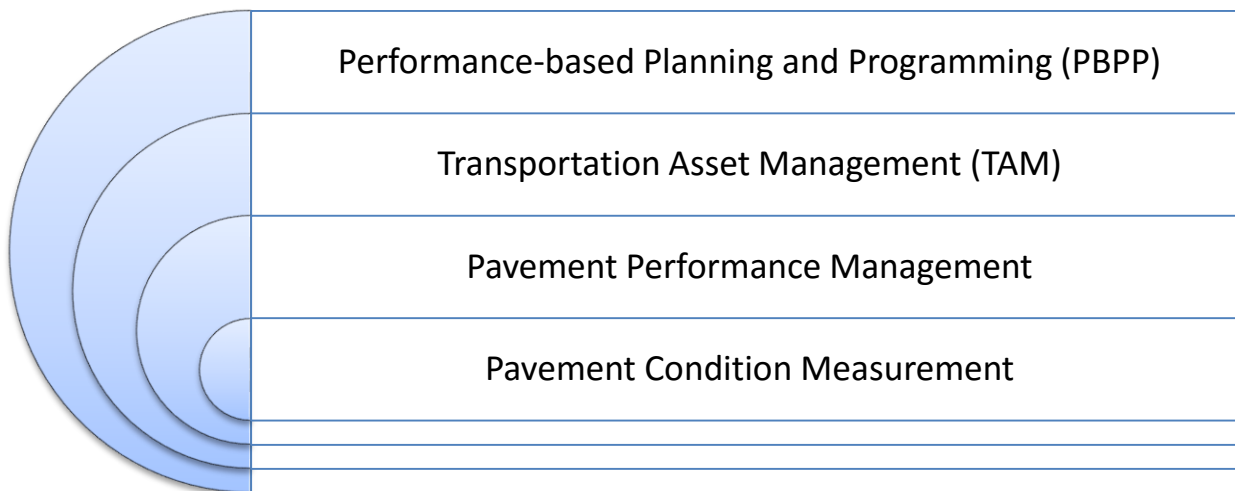


FIGURE 1: HIERARCHY OF CONCEPTS DESCRIBED IN THIS CHAPTER

<sup>1</sup> Full title of bill is Moving Ahead for Progress in the 21<sup>st</sup> Century Act.

## 1.1 PERFORMANCE-BASED PLANNING AND PROGRAMMING

*Performance-based planning and programming (PBPP)* refers to the application of performance management within the planning and programming processes of transportation agencies to achieve desired performance outcomes for a multimodal transportation system.<sup>2</sup> This includes a range of activities and products undertaken by a transportation agency together with other agencies, stakeholders, and the public.

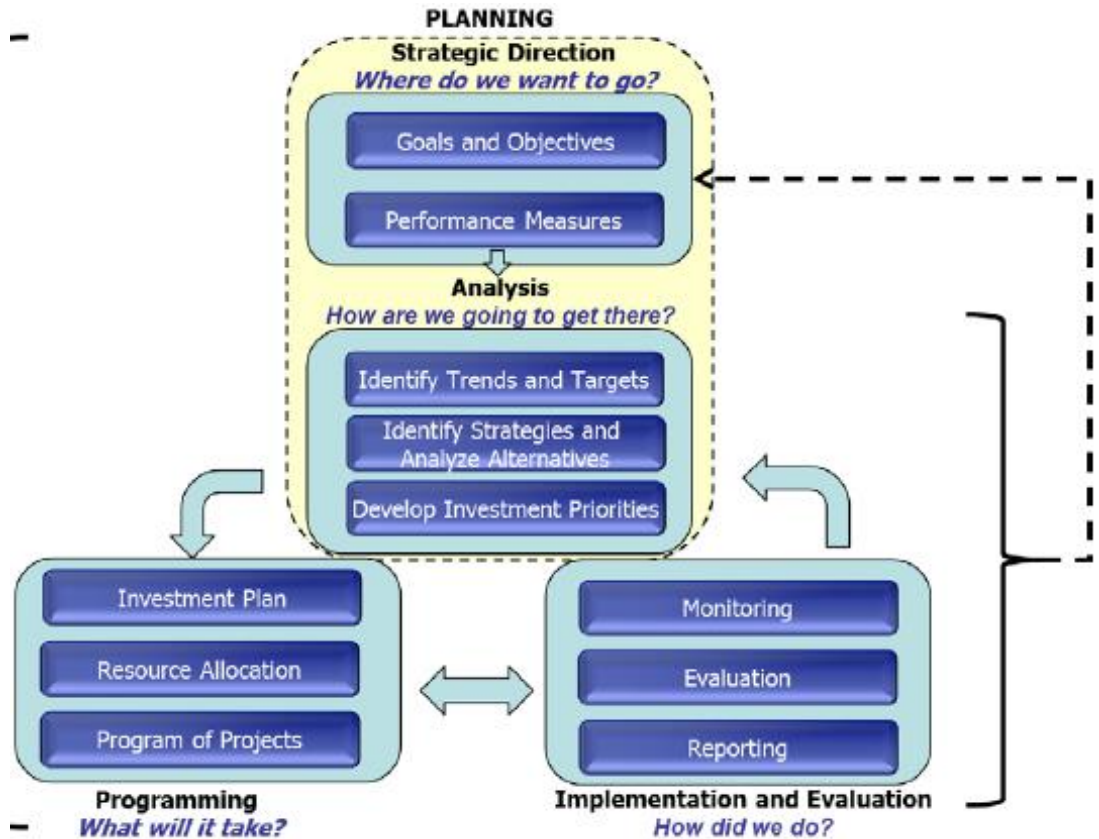


FIGURE 2: FRAMEWORK FOR PERFORMANCE-BASED PLANNING AND PROGRAMMING<sup>3</sup>

PBPP includes the development of a variety of planning documents including long range transportation plans (LRTPs), Strategic Highway Safety Plans, Asset Management Plans, the Congestion Management Process, Transit Agency Asset Management Plans, and Safety Plans. Within the PBPP framework, these plans are explicitly linked to programming documents including State and MPO Transportation Improvement Programs (STIPs and

<sup>2</sup> FHWA Performance-Based Planning and Programming Guidebook (Grant et al. 2013).

<sup>3</sup> *ibid.*

TIPs). PBPP attempts to ensure that transportation investment decisions are made—both in long-term planning and short-term programming of projects—based on their ability to meet established goals, objectives, and targets.<sup>4</sup>

## TERMINOLOGY

In order to have a common understanding of the process of PBPP, it is necessary to develop clear definitions for key terms, as provided in the FHWA *Performance Based Planning and Programming Guidebook*:<sup>5</sup>

- **Goal:** A broad statement that describes a desired end state. *For example: A safe transportation system.*
- **Objective:** A specific, measurable statement that supports achievement of a goal. A good objective should include or lead to development of a performance measure that can be tracked over time and is used to assess different investment or policy alternatives. *For example: Reduce highway fatalities.*
- **Metric/Performance measure:** Data used to assess progress toward meeting an objective. Metrics/Performance measures can be used in strategy analysis to compare different investment or policy alternatives and can be used to track actual performance over time. *Examples: Number of highway fatalities, fatality rate per vehicle mile traveled*
- **Target:** A specific level of performance that is desired to be achieved within a certain timeframe. A target can be used as a basis for comparing progress over time to a desired outcome or for making decisions on investments. *Examples: Reduce fatalities by 5% by 2020. Reduce serious (fatal/incapacitating injury) intersection crashes by 10% by 2020.*

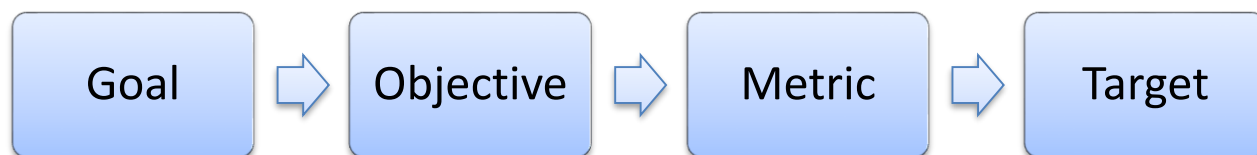


FIGURE 3: RELATIONSHIP OF KEY TERMS IN PERFORMANCE-BASED PLANNING AND PROGRAMMING<sup>6</sup>

<sup>4</sup> Grant et al. 2013.

<sup>5</sup> *ibid.*

<sup>6</sup> *ibid.*

## 1.2 TRANSPORTATION ASSET MANAGEMENT

*Asset management* is a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost.<sup>7</sup>

While the scope of data relevant to TAM can be extensive, the core data generally relates to the physical condition of the transportation system. Pavement is only one of the many physical infrastructure assets managed by transportation agencies, though it is usually the most significant asset by value. Table 1 outlines an example of core data for a robust TAM program.

TABLE 1: PHYSICAL INFRASTRUCTURE ASSETS TYPICALLY INCLUDED IN COMPREHENSIVE TRANSPORTATION ASSET MANAGEMENT PROGRAM<sup>8</sup>

Physical Asset Type	Example Data Types
<b>Pavement (this report)</b>	Distress (Cracking, Rutting, Faulting), Roughness (IRI), Structural adequacy, Design specifications, Construction history, Maintenance history, Average Daily Traffic, Average Daily Truck Traffic
<b>Bridges</b>	Structural adequacy (NBI Rating), Design specifications, Construction history, Maintenance history, Average daily traffic, Average daily truck traffic
<b>Signage</b>	Condition, Reflectivity, Installation and maintenance history
<b>Electronic Signals</b>	Condition, Efficacy, Installation and maintenance history, Energy use
<b>Pavement Markings/ Delineators</b>	Condition, Installation and maintenance history
<b>Guardrails</b>	Condition, Installation and maintenance history
<b>Drainage</b>	Condition, Efficacy, Design details, Environmental impact, Construction and maintenance history
<b>Lighting</b>	Condition, Efficacy, Energy usage, Environmental impact, Installation and maintenance history
<b>ITS Roadside Equip. and Communications</b>	Condition, Efficacy, Installation and maintenance history

### STATEWIDE TRANSPORTATION ASSET MANAGEMENT PLAN

Prior to MAP-21, there were no requirements for state DOTs to demonstrate that their transportation program resulted in performance outcomes. MAP-21 mandates that states establish a risk-based performance-driven transportation

<sup>7</sup> 23 USC §101(a)(2).

<sup>8</sup> Adapted from FHWA 2007.

asset management plan (TAMP). This plan shall include strategies leading to a program of projects that supports specific goals and associated metrics.

The state asset management plan will be required within 18 months of promulgation of the final rulemaking for the revised federal-aid highway program. Per statute, the plan will include:<sup>9</sup>

1. A summary listing of the pavement and bridge assets on the National Highway System in the State, including a description of the condition of those assets
2. Asset management objectives and measures
3. Performance gap identification
4. Lifecycle cost and risk management analysis
5. A financial plan
6. Investment strategies

As of March 2016, final rules for transportation asset management planning and pavement performance management have not been officially adopted. However, rules have been proposed and are now being finalized. In addition to pavement and bridge performance measures, the TAMP will include metrics on safety, environmental impact, congestion, and performance. The TAMP will be required only to include pavement and bridge assets on NHS routes, but states are encouraged to include additional routes and transportation assets.<sup>10</sup>

Further information regarding performance-based transportation asset management and pavement performance management is available from the FHWA Asset Management Program Office at <http://www.fhwa.dot.gov/asset/>, and the AASHTO TAM Portal at <http://www.tam-portal.com/>.

## 1.3 PAVEMENT PERFORMANCE MANAGEMENT<sup>11</sup>

A pavement performance management system is a central component in a TAM program. Many transportation agencies have adopted software-based pavement management systems to partially automate tracking and decision-

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<sup>9</sup> 23 U.S.C.USC § 119(e)

<sup>10</sup> 23 CFR Part 490 [ Docket No. FHWA-2013-0053] RIN 2125-AF53

<sup>11</sup> Pavement performance management may also be referred to as pavement life-cycle management, pavement preservation, or simply pavement management. These terms are considered synonymous for the purposes of this report.

support functions of pavement performance management.<sup>12</sup> The goal is a decision-support system that is perpetually gathering data and applying it to achieve optimized system conditions in terms of selected pavement performance metrics.<sup>13</sup>

#### NATIONAL HIGHWAY PERFORMANCE PROGRAM

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As required by statute in MAP-21, FHWA has created the National Highway Performance Program (NHPP) that will replace reporting requirements for the Highway Performance Monitoring System (HPMS).<sup>14</sup> NHPP covers the National Highway System (NHS)—the network of highways determined to be of strategic importance to the nation’s economy, mobility, and defense.

MDOT is responsible for 5,227 miles of NHS, over half of MDOT’s trunkline mileage. Additionally, MAP-21 expanded NHS to include all roads classified as principle arterials—many of which are outside of MDOT jurisdiction. 1,201 miles of NHS mainline (about 19% of Michigan’s total NHS mileage) must now be managed by local transportation authorities.<sup>15</sup> When the NHPP is finalized, both state and MPO asset management practices will have to be updated to accommodate new TAM planning and reporting requirements.

## 1.4 PAVEMENT CONDITION MEASUREMENT (PERFORMANCE INDICATORS)

This report concentrates specifically on the pavement management component of TAM (which also has some implications for bridge management).

#### PRIMARY PAVEMENT DATA CATEGORIES

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Pavement condition and performance generally can be described by four primary data categories:<sup>16</sup>

- Structural Adequacy/Deflection
- Surface Distress
- Serviceability/Ride-quality

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<sup>12</sup> TRB 2009.

<sup>13</sup> FHWA 2007. NHPP will require metrics only on pavement and bridges in the required Transportation Asset Management Plan, but states are encouraged to include additional assets.

<sup>14</sup> 23 U.S.C 119; 23 U.S.C 104(f); 49 USC 5334(i).

<sup>15</sup> [http://mdotcf.state.mi.us/public/maps\\_nfc/nhsmaps.cfm](http://mdotcf.state.mi.us/public/maps_nfc/nhsmaps.cfm), accessed August 2015.

<sup>16</sup> MDOT and CAR 2013.

- Surface Friction

These categories are further discussed below.

### **Structural Adequacy/Deflection**

*Structural adequacy* describes the load-bearing capacity of a pavement. Measuring structural adequacy involves evaluation of deflection data within a context of pavement properties and performance demand. Deflection data collection requires specialized measurement equipment called a deflectometer.<sup>17</sup> Structural adequacy is valuable in forecasting the condition of pavement under predicted loading scenarios.

### **Surface Distress**

*Surface distress* was traditionally assessed via visual sampling of the pavement surface. Historically, these inspections were performed by engineers walking a representative portion of the pavement and recording the type, severity, and extent of defects. Manual collection and classification of distress data is becoming increasingly rare with the advent of automated image recognition software.<sup>18</sup> More than three-dozen distinct types of pavement distresses have been defined;<sup>19</sup> however, only a few metrics are widely measured, including those required for reporting to the National Highway Performance Program (NHPP). These are: percentage cracking,<sup>20</sup> rutting,<sup>21</sup> and faulting.<sup>22</sup>

### **Serviceability/Ride-quality<sup>23</sup>**

*Serviceability* is essentially an evaluation of the pavement interaction with a typical highway vehicle. Similarly, ‘ride-quality’ (smoothness) reflects the

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<sup>17</sup> MDOT and CAR 2013.

<sup>18</sup> <http://nwpma-online.org/presentations/2014/changemethodpavedatacollect-dynatest.pdf> accessed March 2016.

<sup>19</sup> ASTM D6433.

<sup>20</sup> Federal NHPP reporting requires values for cracking length, and cracking percent. A robust TAM database would ideally provide detail on the *type* of cracking observed. For example, in flexible (asphalt) pavements, distresses such as fatigue cracking, longitudinal cracking, and transverse cracking likely indicate different modes of pavement failure and underlying causes.

<sup>21</sup> Rutting is a measurement of depression in the surface of an asphalt pavement, usually caused by plastic deformation of the pavement or base layer.

<sup>22</sup> Faulting is a measurement of vertical movement in a slab of Portland Cement Concrete (PCC) adjacent to a joint or crack.

<sup>23</sup> Also known as ‘smoothness,’ or ‘roughness,’ this metric essentially refers to variation of pavement from ideal planar surface.

experience of human users within such vehicles. Serviceability/ride-quality measures are most often expressed in terms of the International Roughness Index (IRI).<sup>24</sup> IRI will be a required component of the NHPP and state/MPO TAMPs.

### Surface Friction

*Surface friction* relates to the skid-resistance of the pavement. Poor surface friction of a pavement is a safety issue because vehicles might have longer stopping distances or increased likelihood of control loss. Values for friction are complicated by pavement macro-texture (texture that allows drainage in order to prevent hydroplaning), micro-texture (the actual texture of the stone aggregate particles and binder), changes in micro-texture due to aggregate polishing, the tire type (including its rubber composition), and tread pattern.<sup>25</sup>

### SUBJECTIVE PAVEMENT SURFACE RATINGS

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A pavement surface rating (PSR)<sup>26</sup> is an observation-based system used to rate pavements, usually by ‘windshield survey.’<sup>27,28</sup> Various transportation departments have historically developed PSRs as a low-cost method of assessing pavement condition. As PSR scales are inherently subjective, pavement surface ratings are not adaptable to an M-E-based asset management program.<sup>29</sup> Subjective ratings were allowed for some reporting requirements under the HPMS, but will not be allowed under the NHPP.<sup>30</sup>

### SECONDARY PAVEMENT DATA CATEGORIES

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The *primary* pavement data types, discussed above, are direct measurements of pavement condition or performance. Often, such primary metrics are combined and/or manipulated to create a new *secondary* metric. Many transportation agencies have developed formulas to obtain secondary metrics

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<sup>24</sup> MDOT and CAR 2013.

<sup>25</sup> MDOT and CAR 2013.

<sup>26</sup> Defined in FHWA 2015.

<sup>27</sup> The HPMS Field Manual also refers to this as “Present Serviceability Rating..”

<sup>28</sup> Two PSRs are currently used in Michigan, “sufficiency,” and PASER. Sufficiency is a 1-5 scale rating to report condition of trunklines. (Measurement of Sufficiency is scheduled to cease in 2016.) The PSR, ‘PASER’ is currently used in Michigan. PASER is a 1-10 pavement rating scale that has been standardized by TAMC to assess pavement condition statewide.

<sup>29</sup> MDOT and CAR 2013.

<sup>30</sup> PSRs were permitted to substitute for IRI for some NHS reporting requirements, but will no longer be accepted under MAP-21 revisions (FHWA 2015, pp. 362, 366, 387).



such as remaining service life (RSL), or various pavement condition indices (PCIs).

### **Composite Pavement Condition Indices**

Many transportation agencies combine primary metrics—such as surface distress and IRI—to obtain a new, composite index reflecting the overall pavement condition. One established pavement condition index (PCI) was established by the US Army Corps of Engineers and has been standardized by ASTM International.<sup>31,32</sup> Federal reporting (NHPP) requires individual distress metrics to be reported (cracks, rutting, faulting). However, these same metrics are often used to create a composite, secondary metric for internal agency use.<sup>33</sup>

### **Remaining Service Life**

Primary pavement condition and performance metrics provide only a non-temporal (snapshot) assessment of pavement condition. Effective TAM programs must be capable of accurately predicting pavement performance and condition. Such a process requires estimation of a pavement's remaining service life (RSL).

The RSL represents “the period of time under specified site conditions during which a pavement's structural or functional condition is expected to remain within stated limits, provided that appropriate routine and preventative maintenance are carried out.”<sup>34</sup>

RSL is a critical concept within the NHPP and TAM. The prevailing state-of-art for calculating pavement RSL is based on mechanistic-empirical methods as developed by NCHRP Project 1-37A.<sup>35,36</sup> This will be further discussed in Chapter 3.

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<sup>31</sup> ASTM D6433 and ASTM E2840.

<sup>32</sup> MDOT uses an internally -developed composite PCI called the “MDOT Distress Index (DI).” The MDOT DI is subsequently used to calculate RSL.

<sup>33</sup> MDOT’s distress index (DI) is a composite metric calculated from individual distress metrics.

<sup>34</sup> Titus-Glover et al. 2010.

<sup>35</sup> “The Mechanistic-Empirical Design Guide for New and Rehabilitated Pavement Structures.” NCHRP 1-37A. 2004.

<sup>36</sup> MDOT uses a logistical simple-regression-based method to calculate RSL. (Michigan Office of the Auditor General 2012.)

## NATIONAL HIGHWAY PERFORMANCE PROGRAM

Under proposed NHPP requirements, states will be required to report IRI, cracking percent, rutting, and faulting (as with previous HPMS requirements). However, states were previously able to use statistical sampling methods to provide this data on the NHS network. When the new regulations become effective, states will be required to provide full-extent data (no sampling) on an annual basis for the Interstate system, and biennially for non-Interstate NHS routes.

TABLE 2: NATIONAL HIGHWAY PERFORMANCE PROGRAM REPORTING REQUIREMENTS

NHPP Reporting	Interstate NHS	Non-Interstate NHS
<b>Scope</b>	Full extent of mainline highway <sup>37</sup>	
	Rightmost travel lane or one consistent lane within segment if rightmost lane is not available	
	Both directions of travel	One direction of travel
<b>Max Segment Length</b>	0.1 mile	
<b>Frequency</b>	Annual	Biennial
<b>Metrics</b>	International Roughness Index (IRI)	
	Cracking (percent)	
	Rutting (ACC pavements)	
	Faulting (PCC pavements)	

To ensure that pavement condition metrics are collected consistently, FHWA is adopting AASHTO data collection standards. The specific proposed protocols are shown in Table 3, below. The primary metrics described in Table 3 will then be converted to a good/fair/poor rating by FHWA. States and MPOs will be required to set ratings goals in their transportation asset management plans,<sup>38</sup> and may incur more stringent federal oversight and funding restrictions if targets are not met.

<sup>37</sup> Sampling per current HPMS methods will be allowed until 2020.

<sup>38</sup> This is the TAMP described supra Section 1.2.

TABLE 3: NATIONAL HIGHWAY PERFORMANCE PROGRAM REPORTING STANDARDS

Data Metric	Proposed Standard
<b>International Roughness Index (IRI)</b>	AASHTO M328-14 <sup>39</sup> and AASHTO R57-14 <sup>40</sup>
<b>Cracking_Percent<sup>41</sup></b>	AASHTO R55-10 (2013) <sup>42</sup> <i>or</i> AASHTO PP67-14 and PP68-14 <sup>43</sup>
<b>Cracking_Percent (CRCP)</b>	Percent of pavement surface with longitudinal cracking and/or punchouts, spalling, or other visible defects (as described in HPMS Field Manual). <sup>44</sup>
<b>Rutting<sup>45</sup></b>	AASHTO R48-10 (2003) <i>or</i> AASHTO PP69-14 and PP70-14
<b>Faulting<sup>46</sup></b>	AASHTO R36-13

<sup>39</sup> Standard for IRI data collection device

<sup>40</sup> Standard for IRI data collection method

<sup>41</sup> Not applicable to continuously reinforced concrete pavements (CRCP).

<sup>42</sup> Manual cracking data collection

<sup>43</sup> Automated cracking data collection

<sup>44</sup> Transverse cracking is not included in calculation of CRCP cracking\_percent formula.

<sup>45</sup> Applicable only to asphalt pavement (HMA)

<sup>46</sup> Applicable only to jointed Portland cement concrete pavement (PCC)



## 2 INNOVATIVE APPROACHES TO PAVEMENT CONDITION DATA COLLECTION

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Transportation asset management is an increasingly data-based process as new opportunities for data collection arise, known data-collection methods decrease in cost, and researchers find new ways to use data to characterize pavement performance. This chapter introduces new potential sources of data that could be valuable in pavement performance management programs.<sup>47</sup>

### 2.1 SMARTPHONE ACCELEROMETRY INDICES

There have been several research projects aimed at using the accelerometers and GPS receivers in smartphones to derive road roughness measurements. Some projects have aimed at attempting to capture useful data in a limited number of traversals (as opposed to crowdsourcing), as could be performed by agency employees.

#### MDOT/UMTRI DATA PROBE

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MDOT has investigated the possibility of using MDOT maintenance vehicles to obtain pavement condition data. MDOT's research attempted to correlate smartphone accelerometry data with existing pavement metrics (e.g., IRI, PASER). While researchers found some correlation between smartphone accelerometry and IRI, the resulting data was not precise enough to be of use in TAM or pavement condition reporting.<sup>48</sup>

One barrier to MDOT's approach is that the data capture was limited to MDOT fleet vehicles, which could be expected to make only a limited number of passes over most sections of road within a given time period. In fact, MDOT had hoped to capture useable data after only a single pass. Such an approach requires carefully controlling various factors in the data-capture process that are not feasible in typical conditions.<sup>49</sup> A more promising

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<sup>47</sup> The pavement data collection methods discussed in this chapter could be used to augment TAM, but would not likely be capable of replacing data required for federal reporting which must be collected per AASHTO/FHWA standards.

<sup>48</sup> Belzowski 2014; Belzowski 2015. Additionally, such methods would not currently be acceptable for federal reporting even if perfectly correlated to 'true' IRI because NHPP requirements dictate standardized data collection methods as described in Table 3.

<sup>49</sup> MDOT and CAR 2013, pp. 20-21.

approach to using smartphone data to assess pavement condition is to aggregate multiple data points from numerous passes, as discussed below.

### NDSU ROAD IMPACT FACTOR

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The Upper Great Plains Transportation Institute at North Dakota State University (NDSU) has developed a method of using smartphone accelerometry to derive an index of pavement roughness called the road impact factor (RIF). The RIF index has shown to correlate to IRI, but can be derived from any vehicle at any speed.<sup>50</sup> Precision similar to that achieved by a standardized IRI profilometer can be achieved in a limited number of passes (as few as seven) when a single vehicle is used at a relatively consistent speed and the smartphone is precisely mounted within the vehicle.<sup>51</sup> An extension of this method, called time-wavelength-intensity-transform (TWIT) can obtain pavement roughness data with less control over variables, but requires substantially more passes.<sup>52</sup> The TWIT method could be employed in a passive crowdsourcing method, as discussed below.

## 2.2 CROWDSOURCING PAVEMENT CONDITION DATA

### ACTIVE CROWDSOURCED REPORTING

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Many transportation agencies (including MDOT)<sup>53</sup> already crowdsource data on potholes and road issues by allowing system users to report issues via phone or web applications.<sup>54</sup> But such methods cannot easily provide a timely and accurate system-wide perspective. Traditional web reporting tools require the user to manually input relatively detailed location information; many users likely perceive this process as a barrier. Additionally, many users are not familiar with MDOTs trunkline system and the distribution of jurisdiction for public roads between state, county, and local entities.

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<sup>50</sup> Bridgelall and Daleiden 2015.

<sup>51</sup> Such a method would not be acceptable for federal reporting even if perfectly correlated to ‘true’ IRI because NHPP requirements dictate standardized data collection methods as described in Table 3.

<sup>52</sup> Bridgelall 2014.

<sup>53</sup> MDOT maintains a web service to allow users to report potholes on state trunklines: [http://www.michigan.gov/mdot/0,1607,7-151-9615\\_30883\\_30885-69798--,00.html](http://www.michigan.gov/mdot/0,1607,7-151-9615_30883_30885-69798--,00.html), accessed August 2015.

<sup>54</sup> Dennis, Wallace, and Reed 2015.

Crowdsourcing of pavement condition is likely more effective with applications that are able to accept reports across jurisdictions and agencies. Many services offer convenient features such as complaint classification and support in routing citizen reports to appropriate agencies. One such app, SeeClickFix, has become a popular service and has been adopted by many public agencies as an official citizen engagement platform.<sup>55</sup> In the UK, the national government has deployed a pothole reporting app with nationwide scope. UK's app was specifically designed to allow bicyclists to report road conditions that pose a safety hazard to bikes, but the app is available for all road users.<sup>56</sup>

These citizen-reporting crowdsourcing methods are important public-relations tools for transportation agencies. In the absence of sanctioned citizen reporting methods, citizens might opt to self-deploy reporting platforms. Such grassroots platforms could be beneficial, but agencies risk losing control of the process. Such citizen-deployed platforms are often created to publically shame agencies into action.<sup>57,58</sup>

Most existing pothole-reporting mechanisms are focused on reactive operations and maintenance activities. The data is not often stored and incorporated into asset management programs. One challenge in using such methods for TAM is generating enough public participation to obtain useful system-wide data.<sup>59</sup> Another challenge is assuring that the data does not lead to uneven distribution of resources and entrenchment of existing socioeconomic inequalities due to demographic biases in users of such an app.<sup>60</sup> Despite the challenges, if structured and managed properly, the data generated by these citizen reporting systems could provide value in determining recurring problems, patterns, and impact on public satisfaction.

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<sup>55</sup> <http://gov.seeclickfix.com/> accessed August 2015.

<sup>56</sup> <http://www.fillthathole.org.uk/> accessed August 2015.

<sup>57</sup> Ermoshina 2014.

<sup>58</sup> One example of such a shame-based reporting platform is a program in Panama City, implemented by a local television station, that installed sensors in city potholes that recorded each time the pothole was struck by a vehicle and tweeted about the event to local officials.

([http://www.slate.com/blogs/future\\_tense/2015/06/12/potholes\\_in\\_panama\\_city\\_tweet\\_at\\_local\\_government\\_until\\_they\\_get\\_fixed.html](http://www.slate.com/blogs/future_tense/2015/06/12/potholes_in_panama_city_tweet_at_local_government_until_they_get_fixed.html) accessed August 2015.)

<sup>59</sup> One transportation agency in France has contracted with the national post service (which travels nearly all roads within the network) to collect pavement condition data on a network level. (<http://www.sudouest.fr/2014/03/06/le-gers-cartographie-l-etat-de-son-reseau-routier-grace-a-la-poste-1482678-2703.php>, accessed August 2015.)

<sup>60</sup> Kate Crawford. "Think Again: Big Data." *Foreign Policy*. May 10, 2013.

Obtaining such data is more likely with automated (i.e., *passive*) crowdsourcing applications, as discussed below.

### PASSIVE CROWDSOURCED REPORTING

Many research organizations and transportation agencies are pursuing low-cost pavement condition measurement using connected vehicles or devices. Consumer-grade sensors have been shown capable of detecting potholes, rough pavement, and low friction areas.<sup>61</sup> Many research projects have demonstrated the ability of smartphone accelerometry to measure pavement roughness.<sup>62</sup>

#### Roadroid

One instance of a pavement condition monitoring mobile application that has been deployed is called Roadroid. Developed in Sweden, Roadroid uses a combination of vehicle calibration and repeated measurements to obtain usable data. Roadroid data can be collected with a standard Android smart phone and typical passenger vehicle. Frequent data collection allows agencies to monitor roughness changes over time. This can give early warnings of changes and damage, enable new ways to work in the operational road maintenance management, and can serve as a guide for more accurate surveys for strategic asset management and pavement planning. Collected measurement data are wirelessly transferred via a web service to an internet mapping server with spatial filtering functions.<sup>63</sup>

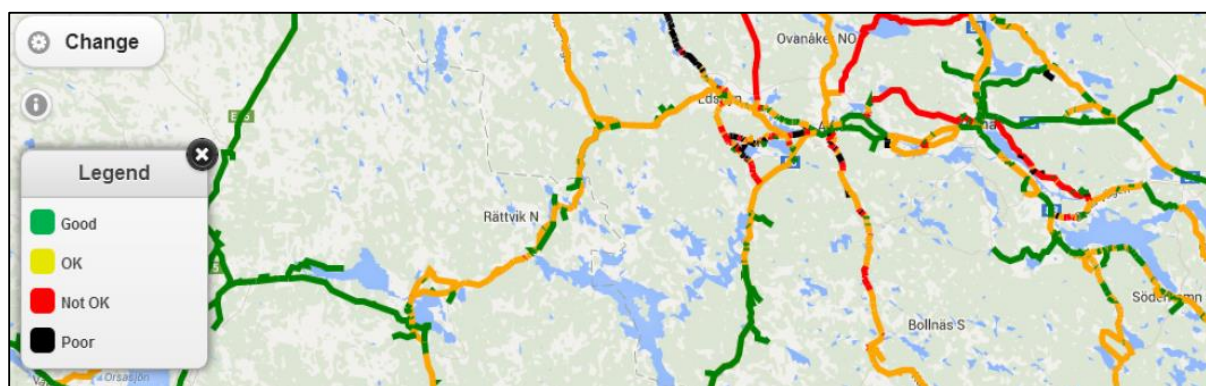


FIGURE 4: ROADROID WEB GIS TOOL SHOWING CROWDSOURCED PAVEMENT CONDITIONS (SOURCE: FORSLÖF AND JONES 2015)

<sup>61</sup> MDOT and CAR 2013.

<sup>62</sup> E.g., Bridgelall 2013; Bridgelall 2014.

<sup>63</sup> <http://www.roadroid.com/>



Roadroid can provide estimated IRI by correlating android smartphone accelerometry data to known vehicle types through experimentally determined formulas, or can allow the user to calibrate IRI measurement to the specific vehicle if an appropriate reference road is available. Roadroid estimated IRI was found to be “moderately correlated” with true IRI ( $R^2=0.515$ ). Roadroid developers acknowledge that this is not an appropriate replacement for precise IRI measurement, but intend the program as a monitoring system and alternative to subjective rating systems.<sup>64</sup> The system has been deployed as a contract service, though developers acknowledge that it would have even higher value as a crowdsourcing application.<sup>65</sup>

Obtaining the required number of data points to monitor an entire road network likely requires crowdsourcing data measurement to public volunteers.<sup>66</sup> Using crowdsourcing to obtain pavement condition would more likely be successful with development and implementation of novel metrics developed specifically to make use of smartphone-based crowdsourced data (rather than attempting to recreate IRI or other existing metric).<sup>67</sup> The most challenging component of such a project would likely be obtaining sufficient public participation.

### **StreetBump**

An example of an application that captures pavement data without trying to approximate pre-existing metrics is StreetBump, deployed by the City of Boston. StreetBump is a smartphone accelerometry-based application to identify potholes. It was originally deployed as a tool for city employees.<sup>68</sup> However, the city opened the application for public use and has collected valuable data from this crowdsourcing effort. For example, the city determined that the majority of recorded “bumps” were related to pavement-embedded castings (e.g., manhole covers, drainage grates, utility grates). These utility infrastructure features are not owned by the city, but by various utility companies. Armed with the StreetBump data demonstrating the impact

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<sup>64</sup> Forsl f and Jones 2015. Such a method would not be acceptable for federal reporting even if perfectly correlated to ‘true’ IRI because NHPP requirements dictate standardized data collection methods as described in Table 3.

<sup>65</sup> Islam et al. 2013.

<sup>66</sup> MDOT and CAR 2013, pp. 21-25.

<sup>67</sup> MDOT and CAR 2013, pp. 27-28.

<sup>68</sup> Carrera, Guerin, and Thorp 2013.

that casting were having on ride quality, the City of Boston was able to pressure utility companies to repair many in-road castings.<sup>69</sup>

Street Bump data is uploaded by users to the city via open311, where back-office software identifies potholes that need to be fixed.<sup>70</sup> The servers to which the app sends data are hosted by Connected Bits, with the data stored in a MongoDB database. City users can generate queries to analyze the data collected in that database.<sup>71</sup> StreetBump’s creators believe that if the app were to demand less interaction from users (e.g., manually starting the app and sending data) the potential for useful data collection would increase.<sup>72</sup>

## 2.3 AUTOMATED VEHICLE SYSTEMS DATA

In most cases, any data generated by automated vehicle systems is solely for internal use of the system.<sup>73</sup> However, this is only a result of architectural design. There are no hard barriers to off-loading vehicle data if system designers allow for it. Developers of automated vehicle systems have begun exploring system and network architectures that would allow for automated vehicle systems to share data with transportation authorities for purposes of pavement condition assessment.

### JAGUAR LAND ROVER PUBLIC DATA RESEARCH

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Jaguar Land Rover is developing a method to detect, predict, and share data on potholes. The pothole system is designed primarily to improve automated vehicle performance (by avoiding potholes). As an added benefit, Jaguar Land Rover’s research team is working with Coventry City Council (UK) to understand how road profile information gathered by this technology could be shared with road authorities, and exactly what data would be most useful for their roads maintenance teams to identify and prioritize repairs.<sup>74</sup>

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<sup>69</sup> Eric Moskowitz. “App shows jarring role of cast-metal covers in Boston.” *The Boston Globe*. December 16, 2012.

<sup>70</sup> open311 (by SeeClickFix) is a citizen-engagement platform available for public agencies. <http://seeclickfix.com/open311/v2> accessed August 2015.

<sup>71</sup> O’Leary 2013.

<sup>72</sup> Carrera, Guerin, and Thorp 2013.

<sup>73</sup> Hong, Wallace, and Krueger 2014.

<sup>74</sup> <http://www.landrover.com/experiences/news/pothole-detection.html>, accessed August 2015

## GOOGLE

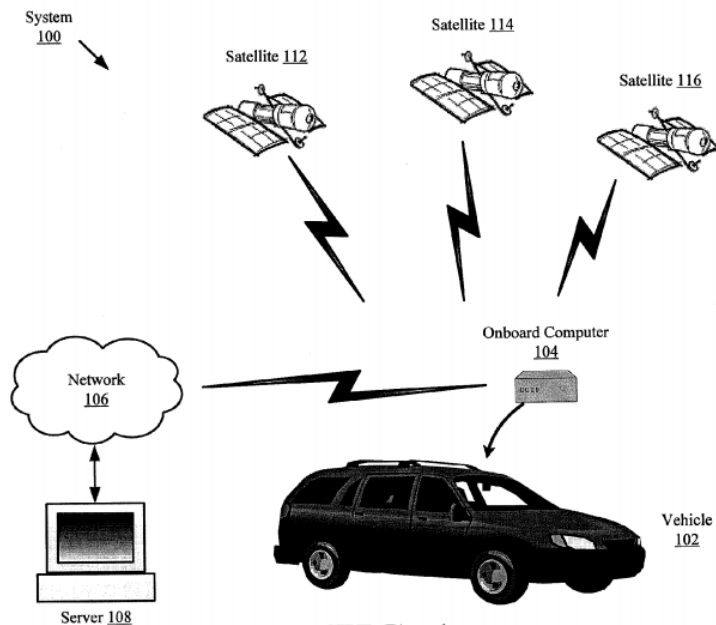


FIGURE 5: GOOGLE PATENT NO. US 9,108,640 B2

Google, now famously developing self-driving cars in California and elsewhere, has filed a patent for “systems and methods for monitoring and reporting road quality.”<sup>75</sup> Google’s patent envisions using embedded vehicle sensors and localization data to continuously monitor road conditions. Programming embedded in the vehicle head unit would convert sensor readings into road-quality metrics and transmit pertinent data through a mobile network to a central server for distribution in road quality reports and to improve driving directions and mapping software.<sup>76</sup>

Google’s patent appears directed at detecting malfunctions in vehicle sensors. However, this system, if implemented, would create a network-wide map of pavement roughness. Between Google’s self-driving car program, and Android Auto (operating system for vehicle head units), Google is well positioned to implement this program at some future date. Transportation agencies should remain aware of Google’s activities in this area and consider engaging with the company for access to any pavement condition data that is generated.

## OTHER POTENTIAL PARTNERS

Jaguar and Google’s interest in developing network-wide pavement roughness data suggests that other automated technology developers might be interested in pursuing similar methods to measure road quality. Mercedes has implemented a cloud-based vehicle-to-vehicle communication system in the E Class sedan to distribute information on travel conditions. Several automakers, including GM, have put substantial effort into reading pavement markings for automated driving. In addition to traditional automotive industry,

<sup>75</sup> Sean O’Kane. “Google could track potholes to help you avoid them down the road.” *The Verge*. August 25, 2015.

<sup>76</sup> Patent No. US 9,108,640 B2. August 8, 2015.

companies known to be developing highly-capable automated vehicle systems include HERE, Uber, and Apple.

## 2.4 IN SITU STRUCTURAL HEALTH MONITORING

Many research projects have experimented with embedding sensors with bridge and pavement infrastructure to measure strain and record load history. MDOT has implemented such sensors as part of a structural health monitoring system on the Cut River Bridge in the upper peninsula.<sup>77</sup> In a separate project, Road Weather Information Systems (RWIS), MDOT has installed temperature and moisture sensors on pavement surfaces and subsurfaces to feed into environmental sensor stations. The data from such sensors is aimed for maintenance crews, but could also be useful for performance management. Such data could be used to precisely measure pavement deterioration rates and develop mechanistic models for pavement deterioration.

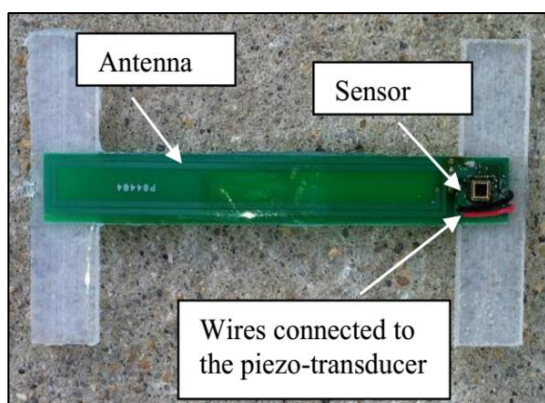


FIGURE 6: SELF-POWERED WIRELESS PAVEMENT STRAIN SENSOR (SOURCE: RHIMI ET AL. 2012)

Infrastructure-embedded sensors are relatively rare, due partially to cost of installation and maintenance. Traditional sensors must be powered and wired, requiring fragile data and power support systems. One potential solution to these issues is the advancement of self-powered sensors. Such sensors operate independent of an external power source by minimizing power requirements and incorporating a permanent long-life battery or capability to harvest kinetic energy (from structural vibration or mechanical strain).<sup>78</sup> Future development of self-powered in-pavement sensors could provide valuable data to pavement performance management programs.

## 2.5 AUTOMATED DISTRESS CLASSIFICATION

Network-level pavement condition assessment is often driven more by reporting requirements than a desire improve pavement performance management. For most reporting, including for the federal NHPP, metrics are converted into general good/fair/poor categories.<sup>79</sup> Classifying pavement

<sup>77</sup> Darwish et al. 2015.

<sup>78</sup> Lajnef et al. 2013.

<sup>79</sup> NHPP requires reporting of individual metrics (IRI, cracking, rutting, faulting) which are *then* translated into a good/fair/poor rating.

condition within such broad categories provides very little data that suggest the mechanisms by which pavement fail, or improvements that could be made to a pavement performance management program. This is particularly true in measures of pavement cracking.

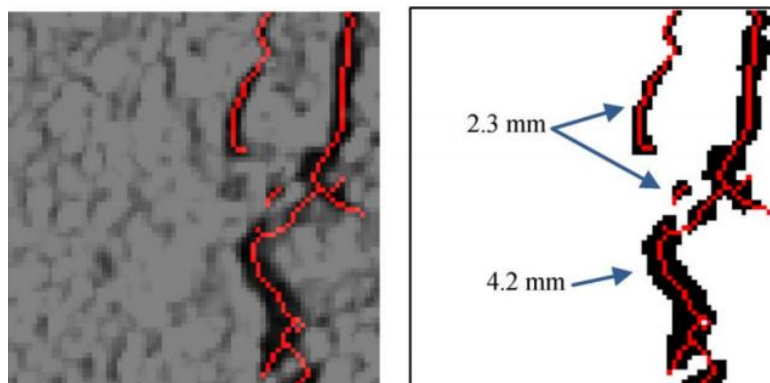


FIGURE 7: AUTOMATED CRACK DETECTION<sup>80</sup>

NHPP requires reporting only the percentage of pavement that is cracking. However, cracking occurs on pavement surfaces for a variety of reasons. Cracks can occur due to excessive loading, climate factors, construction deficiencies, or some combination of these.<sup>81</sup> The pattern of cracking might indicate the mechanism by which it occurred, allowing for improved accuracy in pavement condition forecasting and TAM planning.<sup>82</sup> It is now possible to automatically characterize cracking types, a task previously requiring manual inspection by engineers.<sup>83</sup> Further improvements are possible; electronic image recognition training is an established and advancing methodology.

Vehicle-mounted inertial profilers already collect rutting and IRI data at traffic speed.<sup>84</sup> Some researchers are working on methods to collect similar distress data with low-cost camera vision systems attached to ordinary vehicles. Improved cameras and laser-based techniques allow for detection of cracks that are not apparent to human vision. This could be critical in identifying emerging pavement issues, and in refining mechanistic-empirical models, as pavement cracks usually begin at the bottom of a pavement layer and propagate upward.<sup>85</sup>

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<sup>80</sup> Source: Oliveira and Correia 2013)

<sup>81</sup> ASTM D6433.

<sup>82</sup> Simpson et al. 2013.

<sup>83</sup> Oliveira 2013.

<sup>84</sup> Simpson et al. 2013.

<sup>85</sup> Kutay and Jamrah 2013, p. 19.

While still relatively costly, contract services are available to assess pavement using various imaging technologies such as infrared, radar, lidar, and 3D imaging.<sup>86,87</sup> Data acquisition equipment could be fitted to vehicle-based data acquisition systems, or even unmanned aerial vehicles (UAVs).<sup>88,89</sup> Expanded use of these technologies, as costs allow, would provide improved assessment of pavement structural health and data regarding failure mechanisms and rates. Similar technology could be used to obtain data on a variety of highway assets beyond pavement. Figure 8 shows a lidar-based system capable of capturing roadside asset in addition to pavement distress.

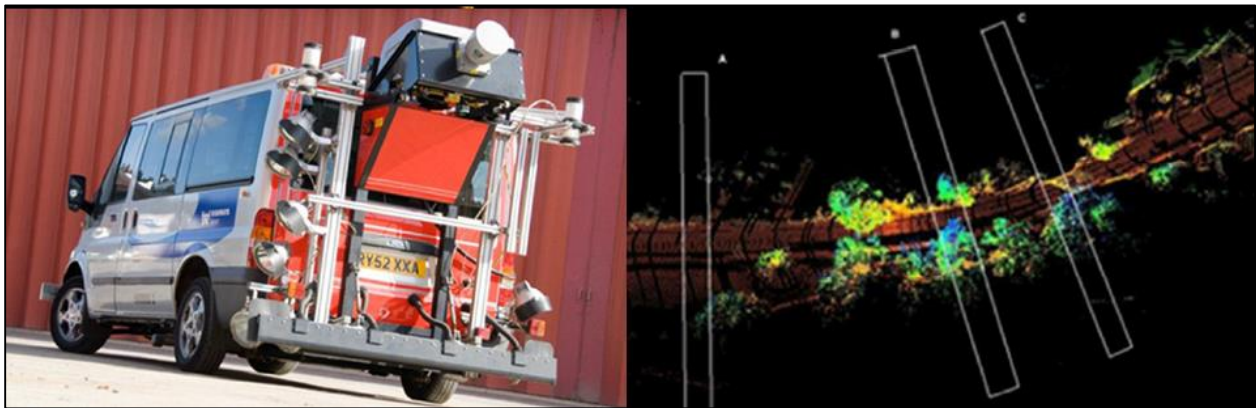


FIGURE 8: LIDAR-FITTED HIGHWAY ASSET DATA COLLECTION VEHICLE<sup>90</sup>

<sup>86</sup> <http://dailycommercialnews.com/Technology/News/2016/2/New-tools-assess-pavement-condition-and-what-lies-beneath-1013766W/> accessed March 2016.

<sup>87</sup> Hong et al. 2012.

<sup>88</sup> Jennifer Donovan. "Michigan Tech researches feasibility of drone use in transportation." *Phys.org*. January 13, 2014.

<sup>89</sup> MDOT Research Spotlight, [http://www.michigan.gov/documents/mdot/ResearchSpotlightRC1616\\_499949\\_7.pdf](http://www.michigan.gov/documents/mdot/ResearchSpotlightRC1616_499949_7.pdf), accessed September 2015.

<sup>90</sup> Wright, Crabb, and Gleeson 2014.

### 3 MECHANISTIC-EMPIRICAL PAVEMENT PERFORMANCE MANAGEMENT

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Data is only valuable if it can be put to good use. Many existing pavement performance management programs were developed for specific data types. Many of these programs have become structured through architecture and practice such that it is difficult to change and adapt to new data types and methods. Most of the novel technologies described in Chapter 2 could not easily be integrated into a pavement management system that is not sufficiently robust.

The state-of-the-practice in pavement performance management is now considered to be a mechanistic-empirical (M-E) approach, administered within a broader performance-based planning and programming framework. An M-E pavement management system is practically required to take advantage of new data sources as described in the previous chapter. M-E pavement performance management is described in this chapter.

#### 3.1 PAVEMENT ENGINEERING AND DESIGN

In the late 1950s, AASHTO conducted a large-scale study to determine how traffic and pavement structure contribute to the deterioration of highway pavements.<sup>91</sup> The results were used to develop the first and subsequent versions of the *AASHTO Guide for Design of Pavement Structures*. Today's demands on the transportation system, however, are significantly different from those that existed half a century ago, and applying classic design approaches to present-day situations has become problematic.

Traditionally, pavement engineers have taken a strictly empirical approach to highway design, which is based exclusively on the results of experimentation and the observation of those results (i.e., empirical evidence). On the other end of the spectrum is the mechanistic design approach, which uses materials characterization and theories of mechanics to relate structural behavior and performance to traffic loading and environmental changes. A mechanistic-empirical approach combines the best of both. In 2004, a National Cooperative Highway Research Program (NCHRP) project developed a new

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<sup>91</sup> Previous to 1973 AASHTO was known as AASHO.

pavement design guide for AASHTO based on a mechanistic-empirical approach.<sup>92</sup>

The resulting *AASHTO Mechanistic-Empirical Pavement Design Guide* (MEPDG) was published in 2008, along with supporting software.<sup>93</sup> The two fundamental differences between the classic *Guide for Design of Pavement Structures* and the MEPDG are that the MEPDG predicts multiple performance indicators, and it provides a direct tie between materials, structural design, construction, climate, traffic, and pavement management systems. Overall, MEPDG outlines a structured design process that has three basic elements:<sup>94</sup>

1. The *model* used to predict critical pavement responses (strains, stresses, deflections, etc.), as a function of traffic and climatic loading (the mechanistic part)
2. *Materials characterization* procedures that support and are consistent with the mechanistic model
3. Defined *relationships* between the critical pavement response parameter and field-observed distress (the empirical part).

The MEPDG provides a uniform and comprehensive set of procedures for the analysis and design of new and rehabilitated pavements. The MEPDG employs common design parameters for traffic, materials, subgrade, climate, and reliability for most pavement types, and can be used to develop alternative designs using a variety of materials and construction procedures. Furthermore, the MEPDG provides recommendations for the structure (layer materials and thickness) of new and rehabilitated pavements, including procedures to select pavement layer thickness, rehabilitation treatments, subsurface drainage, foundation improvement strategies, and other design features.

MDOT adopted the MEPDG for pavement design in 2015.<sup>95</sup> A critical implication of using the MEPDG is that the upcoming federal reporting and planning requirements for NHPP/TAMP have been harmonized with MEPDG performance criteria and default end-of-life values.

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<sup>92</sup> TRB 2004.

<sup>93</sup> AASHTO 2008.

<sup>94</sup> *ibid.*

<sup>95</sup> MDOT 2015a.



### 3.2 PERFORMANCE INDICATORS (PAVEMENT CONDITION MEASUREMENT)

MEPDG is not a direct thickness-design procedure (as was the previous AASHTO Pavement Design Guide). It describes an analysis tool for the designer to use in an iterative approach. The output from the MEPDG is predicted distresses and IRI (smoothness) at a selected reliability level. Specifically, the MEPDG is used to evaluate a trial design (combination of layer types, layer thickness, and design features) for a given set of site conditions and failure criteria at a specified level of reliability. The MEPDG includes transfer functions and regression equations that are used to predict various performance indicators.<sup>96</sup>

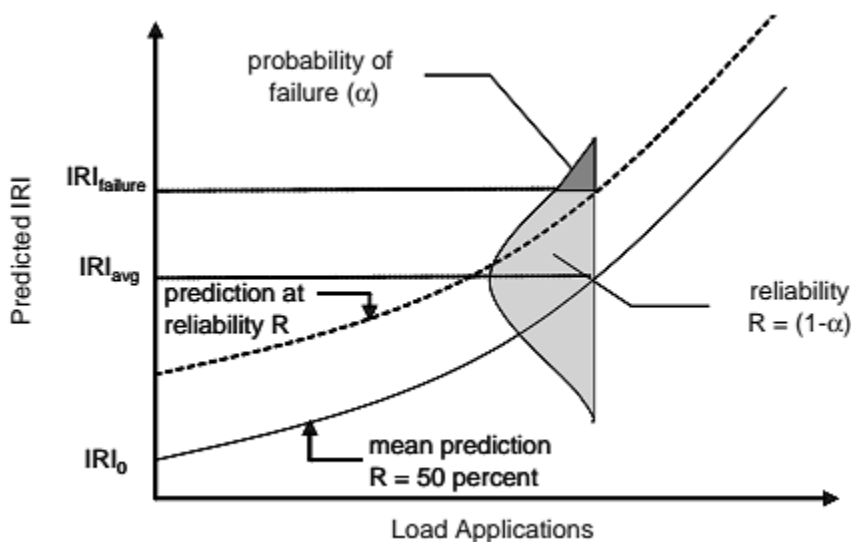


FIGURE 9: MEPDG OUTPUT—PREDICTED IRI AND RELIABILITY (SOURCE: AASHTO 2008)<sup>97</sup>

<sup>96</sup> IRI and the primary distresses predicted by the MEPDG model have been selected by FHWA as required reporting for the NHPP.

<sup>97</sup> In the MEPDG, IRI is predicted empirically as a function of pavement distresses, site factors, and initial IRI (AASHTO 2008, p. 30.)

The specific performance indicators predicted by the MEPDG are as follows:<sup>98</sup>

#### FOR ASPHALT PAVEMENT<sup>99</sup>

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1. Total rut depth and relative impact from individual layers
2. Non-load-related transverse cracking
3. Load-related alligator cracking (bottom initiated cracks)
4. Load-related longitudinal cracking (surface initiated cracks)
5. Reflection cracking in HMA overlays
6. Smoothness (IRI)

#### FOR RIGID (PCC) JOINTED PLAIN CONCRETE PAVEMENT<sup>100</sup>

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1. Mean joint faulting
2. Joint load transfer efficiency (LTE)
3. Load-related transverse slab cracking (includes both bottom and surface initiated cracks)
4. Joint spalling (also embedded into the IRI prediction model)
5. Smoothness (IRI)

#### FOR RIGID (PCC) CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (CRCP)<sup>101</sup>

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1. Crack spacing and crack width
2. Load transfer efficiency (LTE)
3. Punchouts
4. Smoothness (IRI)

Not all performance indicators predicted by the MEPDG must necessarily be used as design criteria. Pavement engineers and TAM planners can adjust the inputs based on available data. The performance criteria recommended as design criteria are given in Table 4 on the following page.

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<sup>98</sup> AASHTO 2008, pp. 15-16.

<sup>99</sup> Total rutting, percent cracking, and IRI are required for all NHS routes under federal TAMP/NHPP requirements.

<sup>100</sup> Total faulting, percent cracking, and IRI are required for all NHS routes under federal TAMP/NHPP requirements.

<sup>101</sup> Percent cracking (including punchouts and spalling) and IRI are required for all NHS routes under federal TAMP/NHPP requirements.

TABLE 4: DESIGN CRITERIA (THRESHOLD VALUES) RECOMMENDED FOR PAVEMENT DESIGN BY MEPDG (AASHTO 2008, p. 74)

Pavement Type	Performance Criteria	Maximum Value at End of Design Life
HMA	Alligator cracking (HMA bottom-up cracking)	Interstate: 10% lane area Primary: 20% lane area Secondary: 35% lane area
	Rut depth	Interstate: 0.40 in Primary: 0.50 in Others (>45 mph): 0.50 in Others (<45 mph): 0.65 in
	Transverse (thermal) cracking)	Interstate: 500 ft/mi Primary: 700 ft/mi Secondary: 700 ft/mi
	IRI	Interstate: 160 in/mi Primary: 200 in/mi Secondary: 200 in/mile
PCC	Mean joint faulting	Interstate: 0.15 in Primary: 0.20 in Secondary: 0.25 in
	Percent transverse slab cracking	Interstate: 10% Primary: 15% Secondary: 20%
	IRI	Interstate: 160 in/mi Primary: 200 in/mi Secondary: 200 in/mile

### 3.3 CALIBRATION

Pavement-ME design software includes default pavement distress models to predict performance over a pavement life cycle. The adoption of an effective mechanistic-empirical pavement design program requires determining local bias in the Pavement-ME global distress models, establishing the causes of such bias whenever possible, and updating the default settings with local calibration coefficients for each distress and IRI prediction model.<sup>102</sup> The corrected coefficients are estimated by minimizing the error between predicted and measured distress.

Obtaining all inputs for the pavement design process can be time-consuming, but these data are what improves the MEPDG over other design procedures. Additionally, the MEPDG allows for variability in the design process when data is not available. MEPDG allows pavement engineers to determine design

<sup>102</sup> Buch et al. 2013, p. 4.

coefficients using a hierarchical structure in which the effort required to quantify a given input is selected based on the importance of the project, importance of the input, and the resources at the disposal of the user.<sup>103</sup>

Pavement-ME allows for local calibration of climate and geological factors, subject to available data. Most important is local calibration of traffic impact, as discussed in the following section.

### 3.4 TRAFFIC MODELLING

Most pavement distresses are caused by repeated truck traffic loads.<sup>104</sup> Characterization of truck traffic is a key data element for structural design of pavement. Accordingly, the MEPDG allows for detailed classification of traffic patterns expected over the life of the pavement.

#### ROADWAY-SPECIFIC INPUTS<sup>105</sup>

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1. *Initial Two-Way Average Annual Daily Truck Traffic (AADTT)*—AADTT has a significant effect on the predicted pavement performance indicators and represents a weighted average between weekday and weekend truck traffic. AADTT can be obtained from WIM data, automated vehicle counters, or manual traffic counts. The value entered into the MEPDG software is the forecasted AADTT after the roadway is opened to traffic or the rehabilitation has been completed.
2. *Percent Trucks in Design Lane*—The percent of truck in the design lane typically is determined by estimating the percentage of truck traffic in the design lane relative to all truck traffic in one direction. However, the definition used in the MEPDG is slightly different; it is defined by the primary truck class for the roadway.
3. *Percent Trucks in Design Direction*—This value represents the percent of trucks in the design direction relative to all trucks using the roadway in both directions. This value can be estimated from AVC data or manual vehicle count data.
4. *Operational Speed*—Truck speed has affects the predicted dynamic modulus ( $E^*$ ) of HMA and, thus, resulting distresses. Lower speeds result

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<sup>103</sup> AASHTO 2008.

<sup>104</sup> Some distresses can be caused, or exacerbated, by climactic and/or geological factors. Pavement damage caused by light vehicles is typically minimal (TRB 2002).

<sup>105</sup> AASHTO 2008, pp. 79-80.

in higher incremental damage values calculated by the MEPDG (more fatigue cracking and deeper ruts or faulting). Thus, the posted truck speed limit can be used to evaluate trial designs, unless the pavement is located in a special low-speed area.

5. *Growth of Truck Traffic*—The truck class mix forecast has a significant effect of predicted pavement performance and can be determined with information about the commodities being transported through the project location. The growth of truck traffic is difficult to estimate accurately because many site and social-economic factors are relevant that are difficult, if not impossible, to predict over 20 years or more. The traffic or planning departments (or both) within an agency can be consulted to estimate the increase in truck traffic over time.

#### WEIGH-IN-MOTION-EXTRACTED INPUTS<sup>106</sup>

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1. *Axle-Load Spectra*—A histogram or distribution of axle loads for a specific axle type (single, tandem, tridem, and quad). In other words, the number of axle applications within a specific axle-load range, as obtained from weigh-in-motion data.
2. *Hourly Distribution Factors*—The percentage of trucks using a facility for each hour of the day.
3. *Monthly Distribution Factors*—This value defines the distribution of truck volumes on a monthly basis in a typical year.
4. *Normalized Axle-Load Spectra*—The normalized axle-load spectra is a normalized histogram of axle loads for a specific axle type. To determine the normalized load spectra, the number of axle applications weighed within a specific load range for an axle type is divided by the total number of axles weighed for that axle type.
5. *Normalized Truck Volume Distribution*—The normalized truck volume distribution is a normalized distribution of the different truck classes within the traffic stream. To determine the normalized truck class volume distribution, the number of trucks counted within a specific classification is divided by the total number of trucks counted.

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<sup>106</sup> AASHTO 2008, pp. 80-82.

6. *Truck Classification Distribution*—The distribution of the number of truck applications for each truck classification for all trucks counted. Trucks are defined as vehicle classes 4 through 13 using the FHWA classifications.

Finally, the MEPDG provides (7.) a *Truck Traffic Classification (TTC) group* rating. This index defines 17 unique TTC groups with normalized axle-load spectra and truck volume distribution, derived from observed count data. Based on TTC rating, the MEPDG provides default values for the normalized axle-load spectra and normalized truck classification volume distributions. These values would ideally be adjusted to local traffic projections, subject to available data (data items 1-6).



FIGURE 10: MOST HIGHWAY PAVEMENT DAMAGE IS CAUSED BY HEAVY TRUCKS

### 3.5 PAVEMENT MANAGEMENT SYSTEMS

Most state transportation agencies, including MDOT, employ pavement management system (PMS) software for decision support in selection of highway projects. A pavement management system allows agencies to make better investment decisions by projecting and minimizing network-level life-cycle costs, rather than adopting a simple ‘worst-first’ approach.<sup>107</sup> Strategic maintenance might require treating pavement when they are still in good condition—before the pavement shows signs of structural failure.

Appropriately using PMS software for pavements designed with MEPDG methods requires adopting MEPDG performance indicators.<sup>108</sup> A rehabilitation strategy should not be pursued without first determining the

<sup>107</sup> Tan and Cheng 2011.

<sup>108</sup> AASHTO 2008, p. 24; Also see *supra*, section 3.2.

causes and mechanisms of the distress.<sup>109</sup> Pavement management frameworks that do not adopt established MEPDG metrics are not capable of taking advantage of improved modelling capabilities of M-E design. Pavement management systems should include regular assessment of MEPDG performance design criteria, as shown in Table 4 on page 27.

Under federal regulatory guidelines established by MAP-21 and confirmed by the FAST Act, state transportation departments and MPOs will be responsible to develop a transportation asset management plan (TAMP) that includes PMS tools that utilize the metrics emphasized in the MEPDG. The TAMP will be required to include at minimum bridge and pavement assets of the NHS. However, agencies that wish to apply TAM to other assets are encouraged to do so within the framework of the federally-required TAMP.

### FHWA PAVEMENT HEALTH TRACK

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The FHWA has developed the Pavement Health Track (PHT) Analysis Tool to determine the health of a pavement network in terms of the pavement's RSL using models developed by FHWA for the Highway Economic Requirements System (HERS)<sup>110</sup> and the National Pavement Cost Models. These pavement performance models are simplified versions of the models and procedures used in the AASHTO MEPDG.<sup>111</sup>

Pavement health can be determined for different pavement types under various conditions such as climate or whether it is in a rural or urban environment. RSL can be reported as both the weighted average RSL of all distresses or as the RSL for one particular distress for a given section of pavement or the entire network. The program provides an option for inputs on material properties, climate, and loading to predict the future remaining service life of the pavement. If the data is not available, the program contains a compiled data set that uses data from such sources as the FHWA Long-Term Pavement Performance program and National Climate Data Center databases as default inputs. This compiled data set meets the needs of the RSL predictive models.<sup>112</sup>

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<sup>109</sup> Buch et al. 2013, pp. 21-28.

<sup>110</sup> HERS-ST is an engineering/economic analysis (EEA) tool that uses engineering standards to identify highway deficiencies, and then applies economic criteria to select the most cost-effective mix of improvements for system-wide implementation (<https://www.fhwa.dot.gov/infrastructure/asstmgmt/hersindex.cfm> accessed April 2016).

<sup>111</sup> <https://www.fhwa.dot.gov/publications/focus/10aug/01.cfm> accessed April 2016.

<sup>112</sup> *ibid.*

A modular design allows for future expansion of the software's capabilities, including adding such features as the ability to develop and display the bridge health index for a particular corridor and to estimate pavement asset values, the impact of various maintenance and rehabilitation plans on RSL, and reconstruction needs. Additional future capabilities could include the ability to detect uneven distribution of RSL, integrate benefit and cost models from HERS, and incorporate State-specific pavement models or calibrated pavement performance coefficients.<sup>113,114</sup>

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<sup>113</sup> *ibid.*

<sup>114</sup> More information regarding Pavement Health Track is available at <https://www.fhwa.dot.gov/pavement/healthtrack/pubs/technical/technical.pdf>.



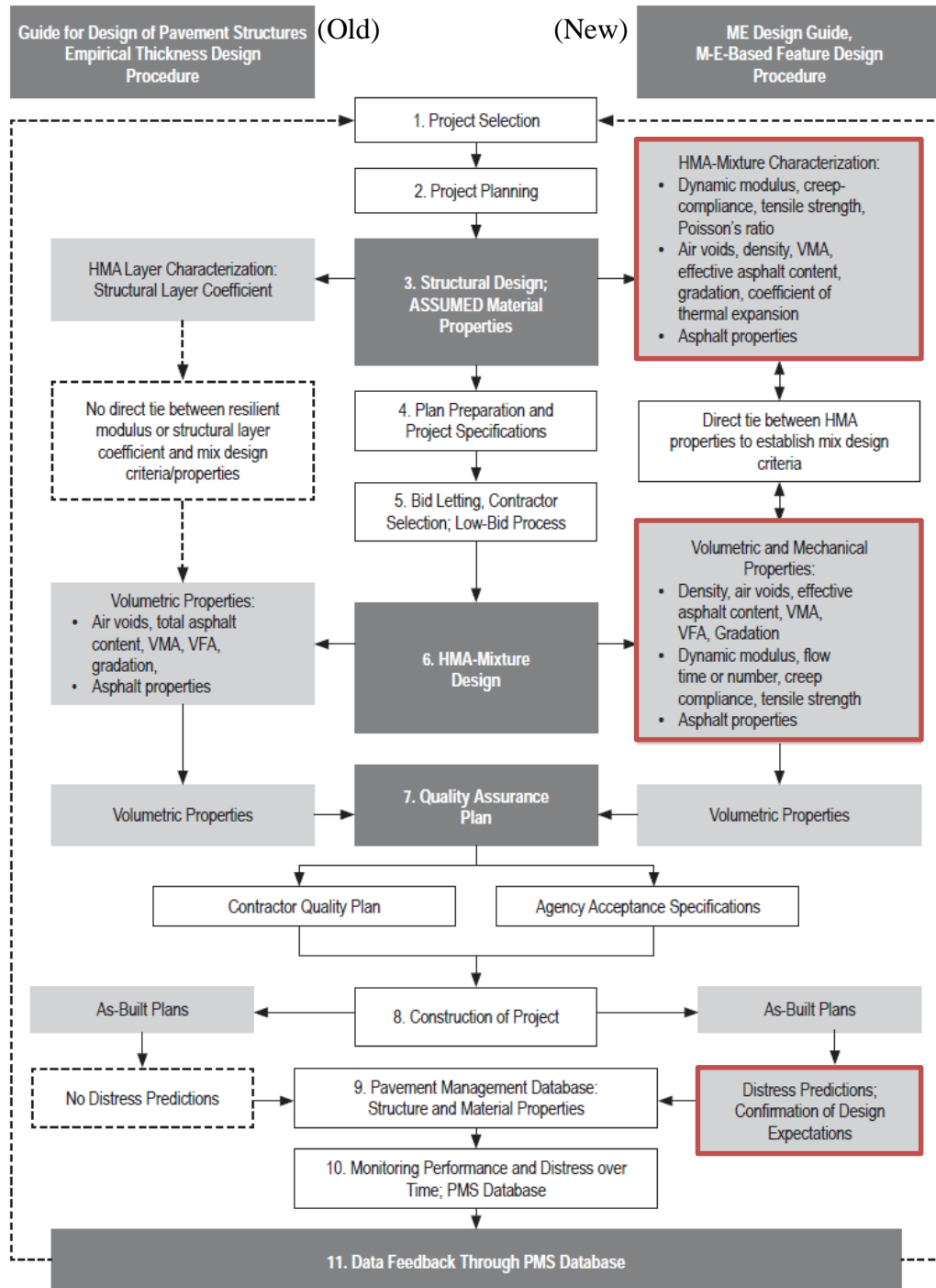


FIGURE 11 TYPICAL DIFFERENCES BETWEEN EMPIRICAL DESIGN PROCEDURES AND AN INTEGRATED M-E DESIGN SYSTEM, IN TERMS OF HMA-MIXTURE CHARACTERIZATION<sup>115</sup>

<sup>115</sup> AASHTO 2008.



## 4 SUMMARY AND DISCUSSION

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Roadway pavement is typically the most significant asset for a transportation agency. Thus, effective pavement performance management is an essential component of a successful Transportation Asset Management (TAM) program. TAM is a decision-making framework designed to optimize transportation investment.<sup>116</sup>

As technology advances, transportation agencies have an expanding array of potential new approaches to obtain data about pavement condition.<sup>117</sup> However, the types of data most useful to assessing pavement condition have long been established, and most methods at acquiring such data have been standardized. While there are expanding possibilities to collect new types of data, far more potential exists to improve existing TAM programs by making better use of existing metrics.

FHWA and AASHTO have recognized the state-of-the-practice in pavement performance management to include mechanistic-empirical approaches within a broad performance-based planning and programming (PBPP) framework.

### 4.1 ADOPTING PERFORMANCE-BASED PLANNING AND PROGRAMMING ACROSS THE ENTERPRISE

State DOTs and MPOs will be required to adopt a basic M-E TAM program within a PBPP framework through development of a Transportation Asset Management Plan (TAMP) for the National Highway System (NHS). Such principles represent recognized best practices in TAM and should be embraced broadly within agencies.

#### PAVEMENT DESIGN AND ENGINEERING

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MDOT transitioned to M-E pavement design in Spring 2015. MDOT pavement engineers now use Pavement-ME, an AASHTOware software product that enables use of the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG).<sup>118</sup>

Pavement-ME allows MDOT engineers to design pavement based on M-E prediction of specific distresses over time, accounting for degradation by

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<sup>116</sup> *supra* Section 1.2, p. 2.

<sup>117</sup> *supra* Chapter 2, p. 10.

<sup>118</sup> MDOT 2015.

weather and traffic loading based on mechanistic-empirical models. A number of different material inputs are required, and accurate measurement of these inputs is crucial for the accuracy of the distress predictions.

Per revisions to the Federal Highway Aid Program introduced in MAP-21 and reaffirmed by the FAST Act, MDOT and Michigan's MPOs will be required to develop a Transportation Asset Management Plan (TAMP) incorporating PBPP principles for the National Highway System (NHS) that incorporates MEPDG metrics and methods. Fully realizing the benefits of the MEPDG will require broad institutional adaption within MDOT, including pavement performance management beyond NHS facilities.

### PROJECT SELECTION AND PROGRAMMING

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As discussed above, MDOT has enabled state-of-the-practice pavement design by adopting the AASHTO MEPDG and supporting software. This approach can enable MDOT pavement engineers to optimize pavement design for local conditions and continually improve design parameters, but it might not result in improvement in pavement life-cycle performance unless asset management and maintenance activities also adopt mechanistic-empirical frameworks.

Many of the metrics that MDOT currently uses to assess the life-cycle performance and condition of pavement are incongruent with M-E theory. The MEPDG model assumes that all distress types are uncoupled.<sup>119</sup> Thus, composite pavement metrics such as DI and PASER cannot be used in mechanistic-empirical pavement performance management.<sup>120,121</sup>

MDOT currently calculates RSL from a composite distress index (DI), and is able to estimate pavement condition degradation reasonably well at the aggregated (state-wide) system-level. However, the performance of individual projects can vary significantly. Using empirical methods only, MDOT is not able to predict the performance of a specific pavement section, or determine causes of variations in pavement performance.<sup>122</sup> Further, appropriate rehabilitation or maintenance strategies cannot be determined without additional data; MDOT currently obtains such data in a “project scoping”

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<sup>119</sup> Buch et al. 2013, p. 4.

<sup>120</sup> Buch et al. 2013; Abu-Lebdeh et al. 2003.

<sup>121</sup> In contrast to M-E approach, MDOT pavement condition forecast models are simple logistic regression models with pavement age as the independent variable (Abu-Lebdeh et al. 2003).

<sup>122</sup> Abu-Lebdeh et al. 2003.

process that is initiated only *after* the pavement section has been selected for replacement or rehabilitation.<sup>123</sup> A mechanistic-empirical TAM system would assist MDOT in identifying investment strategies that would achieve maximum return on investment *before* a project is selected, and allow MDOT to adopt best-practices in performance-based planning and programming (PBPP).

## MDOT TRANSPORTATION ASSET MANAGEMENT

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MDOT will be required to use M-E metrics and principles to develop a Transportation Asset Management Plan (TAMP) under statutory requirements of MAP-21 and the FAST Act.<sup>124</sup> The TAMP will be required only for NHS routes, but states and MPOs are encouraged to include other transportation assets within the plan. When MDOT develops a TAMP, the plan should include all MDOT routes within a single framework. It will be inefficient to have parallel TAM programs for the NHS and for the rest of MDOT's pavement system. MDOT should leverage the expertise and assistance provided by FHWA to develop a state TAMP that is truly statewide—including non-NHS routes.

Optimal pavement performance management is a comprehensive data-based process. The efficacy of the MEPDG process for rehabilitation design hinges on the availability and compatibility of performance (distress and roughness) data, as well as various site-specific data.<sup>125</sup> A rehabilitation strategy should not be pursued with determining the causes and mechanisms of the distress.<sup>126</sup> An ideal pavement management system would consist of a single database integrating multiple data sets, such as those shown in Table 5.

Legacy practices involving calculation of DI and PASER would be duplicative and could be phased-out. With adoption and continued application of MEPDG design and performance management in coming years, MDOT will be able to continually improve investment strategies as life-cycle models are refined to reflect local performance.

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<sup>123</sup> MDOT 2015b.

<sup>124</sup> FHWA. MEMO: INFORMATION: National Highway Performance Program (NHPP) Implementation Guidance as Revised by the FAST Act. March 9, 2016.

<sup>125</sup> Buch et al. 2013, p. 3.

<sup>126</sup> Buch et al. 2013, pp. 21-28.

TABLE 5: EXAMPLE DATA FOR USE IN M-E PAVEMENT MANAGEMENT SYSTEM

Data Category	Example Data Sets <sup>127</sup>
<b>General and Project Information</b>	Project identities Construction date Restoration date(s) Maintenance date(s) Traffic opening date(s)
<b>Analysis Parameters</b>	Initial smoothness (IRI) Performance criteria (IRI, cracking, and faulting)
<b>Climate Data</b>	Weather station near project, or interpolation of multiple stations if data not available at site
<b>Traffic Data</b>	ADT, ADTT Percent trucks Vehicle speed data Traffic volume and axle adjustment factors Wheel location Traffic wander
<b>Drainage and Surface Properties</b>	Cross-slope Length of drainage path Surface absorptivity
<b>Layer Definition and Material Properties</b>	Number of layers, description, material details Mechanical and thermal properties Traffic history

As suggested by the example data types in Table 5, embracing M-E pavement performance management will require increased data collection efforts across MDOT—necessitating active engagement from all departments involved in any aspect of pavement design, construction, maintenance, performance measurement, planning, and project selection.<sup>128</sup> Legacy TAM frameworks did not require such a detailed amount of data, and consequently MDOT is not currently organized in such a way to facilitate use of such data even when the data exists.

The importance of data collection became apparent when MSU and MDOT researchers evaluated in-field pavement performance in Michigan to calibrate local coefficients for Pavement-ME design software. This calibration process is a critical step in adopting MEPDG and Pavement-ME software. Generally,

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<sup>127</sup> HPMS reporting requires data on only one lane of a multi-lane road. (in both directions for interstate routes). A robust pavement performance management system would go beyond these requirements to capture lane-level data, as many routes have different traffic conditions and subsequent life-cycle performance and maintenance activities in differing lanes.

<sup>128</sup> See Tan and Cheng 2011 for relation to maintenance activities.

the default (nationally calibrated) model does not perform well if the inputs and performance data used to create the default model do not reflect local conditions. When MDOT and MSU researchers began the calibration process for Michigan projects, they found that much of the required data was unavailable. Even when design information was available, tracking it down proved to be arduous. Researchers had to estimate many of the parameters required to develop local models of pavement performance.<sup>129</sup>

The MEPDG calibration process also exposed deficiencies in legacy pavement engineering and condition assessment practices; the team identified several projects that were observed to be failing at a significantly higher rate than expected. The research team and MDOT attempted to identify any construction or material related issues that might explain poor pavement performance, but in all cases, “it was concluded that there was not enough information available to determine why these sections were performing poorly.”<sup>130</sup> Lacking such data, MDOT engineers were unable to appropriately calibrate the MEPDG design coefficients to local conditions.

MDOT’s ability to collect, archive, and access such data must improve to optimize MEPDG design and subsequent TAM practices. Currently, MDOT’s pavement management approach is arranged according to legacy practices in which various aspects of TAM were loosely connected and performed by independent divisions. MDOT has at least four independent statewide operational divisions directly responsible for some aspect of pavement performance management.<sup>131</sup>

- Statewide Planning Division
- Asset Management Division
- Construction Field Services Division
- Operations Field Services Division

These statewide offices are challenged to coordinate across institutional boundaries to develop coherent statewide strategies for pavement performance management. This coordination is made even more difficult as many aspects

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<sup>129</sup> Haider et al. 2014, pp. 67-84.

<sup>130</sup> Haider et al. 2014, p. 63. Because no causes for poor pavement performance could be identified, all pavement sections, including apparent outliers, were included in the calibration model. This is not ideal.

<sup>131</sup> April 2015 MDOT organizational chart, [http://www.michigan.gov/documents/orgchart011603\\_55427\\_7.pdf](http://www.michigan.gov/documents/orgchart011603_55427_7.pdf), accessed September 2015.

of planning, programming, engineering, construction, and maintenance are distributed among MDOT's seven regional offices, twenty transportation service centers (TSCs), and thirty or so maintenance garages.

With previous pavement design and asset management practices, it was often difficult to establish relationships between design, construction, maintenance, and resulting pavement performance. With M-E pavement performance management, any data has the potential to contribute to understanding of pavement mechanics and empirical relationships. The entire history of a pavement should be known if possible, down to the maintenance actions, including reactive maintenance, plowing and salting. Such a wealth of data could overwhelm traditional pavement performance strategies, but intelligent decision-support software based on mechanistic-empirical theory is capable of integrating a wide variety of data types into a coherent and logical asset management plan.<sup>132</sup> Good data becomes much more valuable and is, in fact, essential in this process. This will require MDOT to adjust pavement condition data collection methods to better provide the types of data utilized by M-E theory and the MEPDG.

One benefit of a mechanistic-empirical approach to TAM is that models can be expanded to incorporate a variety of factors beyond pavement performance. The potential scope of TAM is limited only by the availability of data and scope of models. This might allow potential projects to be better assessed for return on investment regarding priorities beyond pavement. For example, consider two potential projects (A and B) with equivalent pavement RSL—with only enough budget for one of the projects within the next five years. *Project A* has been identified as needing stormwater management improvements; however, *Project B* has higher traffic demands and would benefit from added ADA-compliant pedestrian facilities. A sufficiently robust TAMS will be able to incorporate such variables in project identification, selection, and design. Further, such a system would also be amenable to the inclusion of new technology-based data sources such as those discussed in Chapter 2.

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<sup>132</sup> Kutay and Jamrah 2013.



## 4.2 COORDINATION AND GUIDANCE OF STATEWIDE TRANSPORTATION ASSET MANAGEMENT

Municipal Planning Organizations (MPO's), large counties, and large cities are often responsible for the performance of extensive, complex, multimodal transportation networks. In contrast with small and rural localities, these areas would likely benefit from adopting coherent TAM programs incorporating M-E pavement management principles. MPO's will be subject to MAP-21 performance-based planning requirements and national measures with regards to the interstates and NHS. Thus, MPO's will be largely responsible for coordinating county and city planning. However, MDOT is ultimately accountable for the condition of the NHS within MPO boundaries.

FHWA proposes MPOs develop performance targets by either supporting statewide targets, or developing their own.<sup>133</sup> In order to promote a logical and legible statewide TAM program, MPOs should be compelled to have self-contained planning/programming operations that meet federal requirements. To the extent practical, MPOs should mirror MDOT TAM practices, including use of M-E methods to estimate RSL. This is particularly important for project selection on trunklines and NHS facilities.

The AASHTO MEPDG might not be practically applied to all local roads, but the adoption of M-E methods is the most likely way to improve performance results. If there is room to improve investment decisions at the local level, such improvements would be best attained with an M-E approach to pavement performance management. MPOs should adopt M-E pavement design and project selection to extent practical, while transitioning TAM programs to support future expansion to more robust data-intensive methods.

MDOT can encourage a broad transition to PBPP frameworks and M-E TAM by providing support and assistance to county, municipal, and MPO transportation agencies. In addition to having a greater institutional capacity, MDOT will have statewide performance data that will be valuable for smaller agencies when calibrating M-E pavement design and TAM programs.

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<sup>133</sup> FHWA 2015, p. 327.

## REAL-WORLD LIMITATIONS OF PERFORMANCE-BASED PLANNING AND PROGRAMMING

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A theoretical model of PBPP is a top-down administered system with unified goals and targets based on objective system-wide metrics. Such a system can be adopted only partially in real-world scenarios.

MDOT's network of 9,700 miles of state trunkline highways and approximately 4,413 bridges is managed by semi-autonomous regional offices, transportation service centers, and maintenance garages—each with unique regional needs and organizational culture. The state transportation improvement program (STIP) is developed as an amalgam of local and regional priorities identified in the annual “call for projects.” The final STIP is ideally reflective of MDOT-set goals, metrics, priorities, and strategies, but multiple actors influence the way in which MDOT priorities are reflected.

A statewide TAM program is further limited by the scope of MDOT jurisdiction. MDOT has direct authority over only about eight percent of Michigan's total 120,000 or so linear miles of paved roads. The remaining 92% of road mileage is under the jurisdiction of counties and municipalities. These local authorities have asset management programs ranging from fairly robust to informal.<sup>134</sup>

Per federal planning requirements, project selection in metropolitan counties is directed through the representative MPO, of which there are 13 in Michigan. Construction is managed through sub-regional transportation service centers, who often contract projects to county or local agencies, who in turn often subcontract the actual construction. Routine maintenance of trunklines is similarly divided; many maintenance services are performed directly through MDOT maintenance garages, others are contracted to county or local entities, and both MDOT and local agencies sometimes subcontract maintenance tasks.

This division of responsibilities is not necessarily a bad thing, and would be difficult to change in any case. MDOT is divided into regional entities, in part, to allow for local knowledge and priorities to be incorporated into planning and programming. However, this will make adoption of statewide PBPP frameworks difficult. Regional offices and local agencies will necessarily

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<sup>134</sup> County and local agencies are not required to adopt an asset management plan. Municipal agencies (though not counties) are allowed increased flexibility of fund usage if they do develop an approved plan (MDOT and CAR 2013.)

have to decide how to bound the rationality of M-E frameworks within local contexts when responding to the annual statewide call for projects.

### 4.3 LEGISLATIVE OPTIONS FOR MANAGEMENT OF EXPANDED NATIONAL HIGHWAY SYSTEM

MAP-21 expanded the NHS to include all principle arterials. As a result, the state of Michigan is now ultimately responsible for the condition of 1,200 miles of pavement (as well as multiple bridges) owned by county or local agencies. This is about 19% of NHS mileage statewide, and will be factored into consideration when FHWA determines if Michigan is meeting performance targets.

Considering that federal transportation funds might be influenced by NHS performance measurements, Michigan could explore legislative approaches to encourage local agencies to maintain NHS routes in good condition. For example, municipalities could be compelled to dedicate a greater percentage of state transportation funding on NHS routes until performance targets are attained. Such provisions would be especially important for NHS-route bridge and culvert conditions.<sup>135</sup>

### 4.4 CROWDSOURCING PAVEMENT PERFORMANCE MEASUREMENT

A statewide transition to M-E pavement performance management principles imposes challenges for data collection. The only way to improve pavement performance and related investment decisions is to acquire enough data to improve mechanistic-empirical pavement life-cycle models. Ideally, all data types used by the MEPDG would be available for the entire system. Unfortunately, this is not a realistic expectation, particularly for county and local networks.

It would be very valuable to obtain a metric that could be consistently collected for all public roads within the State of Michigan to provide an objective network-level assessment of pavement condition. Regularly collecting MEPDG metrics such as IRI and cracking would be cost-prohibitive—and probably not necessary on low-volume roads.

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<sup>135</sup> FHWA 2015, pp. 373-377.

MDOT should explore deploying crowdsourcing methods, taking advantage of smartphones and public volunteers, as an alternative to traditional pavement data collection methods. The power of crowdsourced data is that large data sets—collected from multiple sources—negates limitations in generalizability of a single data source. Aggregated data should provide a reasonably accurate model of the roadway system in relation to how an average user experiences the system.<sup>136</sup> Further, it is possible that this data may correlate well to primary pavement performance metrics such as IRI.<sup>137</sup>

While crowdsourced data cannot provide a direct replacement for any current metric, such data could be more valuable for a customer-service approach to TAM than are traditional measures. Essential to TAM is creating the optimum experience for users/customers of the transportation system with minimum cost. Current objective measures relating to the ride-quality/serviceability of pavement, such as IRI, generally create a model of the pavement from which the ride quality is inferred. Subjective measures, on the other hand, use human judgment to assess serviceability/ride-quality, but provide little value to a mechanistic-empirical approach to TAM. Smartphone accelerometry data could provide the best attributes of both data types; measuring serviceability in an aggregated, but direct, objective metric.<sup>138</sup> For example, crowdsourced smartphone accelerometry could provide a measure of ‘pseudo-IRI’ for the entire statewide network that could be correlated with true IRI collected for the National Highway Performance Program. Crowdsourced pseudo-IRI could not be used reporting/managing the NHS because NHPP explicitly requires AASHTO standardized methods of data collection.<sup>139</sup> However, pseudo-IRI would allow MDOT to obtain a comparable metric for the rest of the statewide network—improving the scope and utility of the Transportation Asset Management Plan.<sup>140</sup>

One significant advantage of continuous crowdsourced data collection is the potential to capture transient variations in pavement condition. Climate and weather interacts with pavement in multiple ways. Pavements are subject to

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<sup>136</sup> MDOT and CAR 2013.

<sup>137</sup> *ibid.* See also MDOT and CAR 2013.

<sup>138</sup> MDOT and CAR 2013.

<sup>139</sup> It is possible that future revisions of the Federal Aid Highway Program could allow for developing crowdsourced methods to substitute for traditional data collection if such methods prove useful and accurate.

<sup>140</sup> Network-wide pavement condition measurement for all paved roads within the state is currently performed with the subjective PASER scale. This metric is not amenable to use in an M-E-based asset management system as will be required for the NHS.

seasonal and diurnal forces that effect various measurements.<sup>141</sup> Collecting data on a continuous basis will detect these cyclical anomalies and add to general understandings of pavement life cycles.<sup>142</sup> Additionally, continual data collection will counteract variances in traditional measures (e.g., rutting, faulting, cracking) that occur when measurements are taken at different times of year, day, temperature. Data that reflect the seasonal development of acute distress points could result in increased accuracy in results from mechanistic-empirically based decision-support software.

A barrier to deploying crowdsourcing methods is attracting a crowd. While the technology that would allow for a smartphone app to generate crowdsourced pseudo-IRI is mature and proven, MDOT would be challenged to recruit enough users to provide enough data to be significant. One possibility may be partnering with consumer-available applications that are already popular with the traveling public. For example, accelerometry data capture could be an extension of a navigation app like Waze. Drivers would opt-in to enable the extension, and would then provide road condition data whenever they use Waze.

## 4.5 CLOSING REMARKS

The USDOT—as well as state and local transportation agencies—have been under pressure for several decades to improve the condition of the nation’s transportation infrastructure. Improving pavement performance first requires the ability to consistently measure pavement condition. Considering this, FHWA has long required objective pavement condition/performance metrics (such as IRI) within the Highway Performance Monitoring System (HPMS). Consistently tracking such metrics enables transportation asset management (TAM) programs to link past investment decisions to objective performance results.

However, FHWA did not explicitly require that states and MPOs link objective performance metrics to investment strategies through pavement management systems or broader TAM programs. While many states

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<sup>141</sup> Simpson et al. 2013.

<sup>142</sup> MDOT’s distress index (DI) measurement occasionally finds pavement sections that spontaneously improve between readings. (e.g., a pavement found to be in fair condition one year might be found to be in good condition two years later, even though no remediate maintenance actions have been taken.) (Abu-Lebdeh 2003, p. 8) Assuming that distress data collection is accurate and consistent, such anomalies could be explained by varying weather conditions at the specific time of data collection.

developed TAM programs that allow future pavement conditions to be forecast at a system-wide scale as related to funding amount, many programs did not utilize mechanistic-empirical (ME) relationships to understand why pavements may prematurely fail or how investment strategies could be improved.

Provisions introduced within MAP-21 and elaborated by the FAST Act will soon require that federal-aid highway funding administered through the new National Highway Performance Program (NHPP) will utilize objective performance-based planning and programming (PBPP). States and MPOs will be required to develop a Transportation Asset Management Plan (TAMP) with explicit targets related to objective metrics such as IRI, percent cracking, rutting, and faulting. FHWA will require the TAMP to cover only pavements and bridges on the National Highway System (NHS). However, FHWA encourages transportation agencies to include a variety of transportation assets within the TAMP, including those other than pavements and outside the NHS.

State DOTs and MPOs would benefit from leveraging the new PBPP requirements to broadly re-configure existing transportation asset management programs. Many existing TAM programs are based on broad metrics (e.g., a composite ‘distress index’) or even subjective ratings (e.g., PASER). Use of such metrics does not allow for mechanical-empirical relationships to be observed that would allow an agency to take advantage of the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) or better forecast pavement performance at the project level. As states and MPOs develop PBPP frameworks and TAMP documents per federal requirements, these frameworks should be embraced across entire agencies. Alternate performance metrics and parallel TAM processes should be discontinued.

New technologies such as wireless sensors and connected vehicle data provide exciting opportunities for agencies to improve TAM processes. However, these technologies will be of greatest benefit within a comprehensive PBPP framework and referenced within an M-E model of pavement life-cycle performance. Transportation agencies should concentrate on reconfiguring legacy TAM frameworks before attempting to utilize new data sources.

The development of state and MPO TAMPs, and related PBPP frameworks, will not likely be a *technical* challenge. FHWA, AASHTO, and research institutions have extensively studied and detailed how to implement such programs, and provide extensive resources for state and local agencies. The primary challenges will likely be the reticence within agencies to transition

away from legacy frameworks and practices that have become embedded in the culture and knowledge-base of an agency.

State DOTs and MPOs should recognize the potential benefits available by fully embracing Performance-based Planning and Programming frameworks, including a comprehensive, risk-based Transportation Asset Management Plan and Mechanical-Empirical pavement performance management. FHWA resources are available to assist in adopting such best-practices, and transportation agencies should implement such changes with enthusiasm.

Further information regarding performance-based TAM and pavement performance management is available from the FHWA Asset Management Program Office at <http://www.fhwa.dot.gov/asset/>, and the AASHTO TAM Portal at <http://www.tam-portal.com/>.





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## APPENDIX A: LIST OF ABBREVIATIONS

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AADTT	Average Annual Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
ADT	Average Daily Traffic
ADTT	Average Daily Truck Traffic
ASTM	Formerly American Society for Testing and Materials. Now known as ASTM International without direct reference to former abbreviation.
CAR	Center for Automotive Research
CRCP	Continuously Reinforced Concrete Pavement
DI	Distress Index
DOT	Department of Transportation
DTMB	[Michigan] Department of Technology, Management, and Budget
FHWA	Federal Highway Administration
ft	Feet
GIS	Geographical Information Systems
HERE	Not an acronym. A digital mapping firm.
HMA	Hot Mix Asphalt
HPMS	Highway Performance Monitoring System
in	Inches
IRI	International Roughness Index
ITS	Intelligent Transportation Systems
LTE	Load Transfer Efficiency
LTPP	Long Term Pavement Performance [Program]
MAP-21	Moving Ahead for Progress in the 21 <sup>st</sup> Century
MDOT	Michigan Department of Transportation
M-E	Mechanistic-Empirical
MEPDG	Mechanistic-Empirical Pavement Design Guide
mi	Miles

MPO	Metropolitan Planning Organization
MSU	Michigan State University
NBI	National Bridge Inventory
NCHRP	National Cooperative Highway Research Program
NDSU	North Dakota State University
NHPP	National Highway Performance Program
NHS	National Highway System
PASER	Pavement Surface Evaluation and Rating
PCC	Portland Cement Concrete
PCI	Pavement Condition Index
PMS	Pavement Management System
PSR	Pavement Surface Rating
$R^2$	Coefficient of Determination (statistical function)
RIF	Road Impact Factor
RSL	Remaining Service Life
STIP	State Transportation Improvement Program
TAM	Transportation Asset Management
TAMP	Transportation Asset Management Plan
TAMS	Transportation Asset Management System
TRB	Transportation Research Board
TSC	Transportation Service Center
TTC	Truck Traffic Classification
TWIT	Time-wavelength-intensity-transform
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
US	United States
VFA	Voids Filled with Asphalt
VMA	Voids in Mineral Aggregate
WIM	Weigh-in-Motion

