NCHRP 20-24(37)G - Technical Guidance for Deploying National Level Performance Measurements

draft final

report

prepared for

National Cooperative Highway Research Program

prepared by

Cambridge Systematics, Inc.

with

Applied Research Associates, Inc.
Michael Fraher, Consultant

The information contained in this report was prepared as part of NCHRP Project 20-24(37)G, National Cooperative Highway Research Program.

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Disclaimer

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Volume 1 - Measure Details

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1.0 Introduction

Responding to recent trends that have placed greater emphasis on public-sector accountability for more effective performance, the American Association of State Highway and Transportation Officials (AASHTO) adopted a federal surface transportation authorization proposal that included a national performance measurement program focused on critical national goals. The proposal is based on the notion that a national performance measurement/management program would:

- Focus needed attention on key national goals;
- Provide more transparency and accountability for the federal program;
- Build on the considerable performance measurement/management work already occurring in individual state DOTs;
- Help make the case for a larger federal program; and
- Drive better performance results through an iterative process of establishing best practices across states and determining which strategies are most effective in each particular goal area.

Consistent with this proposal, AASHTO established seven task forces which have worked for nearly two years to identify performance measures that states could use to track the impact of investments in the national goal areas. This effort has resulted in the designation of three tiers of performance measures for consideration in a national performance-based structure by which states would report annually their performance in these goal areas, using nationally-consistent measures relative to state-developed targets for those measures. The measures in the Table 1.1 Tier matrix were aligned against three criteria:

- Is there general consensus on the definition of the measure?
- Is there a common or centralized approach to data collection in place?
- Has the availability of consistent data across states been established through national comparative analysis or other research effort?

Tier 1 measures meet all three criteria and are considered complete or nearly complete and ready for deployment, with the understanding that there could be further improvements to the measures in the future. Tier 2 measures meet one or two criteria and require further work before they are ready for deployment. Tier 3 measures are generally still in the proposal stage and require further study and input from stakeholders in order to advance through the process of adoption. As some measures are currently more developed nationally, the level of detail for each measure varies. For some formulas are well established, but data issues

must be overcome; for others data sources may be consistent, but field measurement varies.

In Section 2, this report provides the following information for each Tier 1 measure:

- Precise definition of each measure;
- List of specific data items needed for each calculation, details regarding the source for each item and/or standards for collecting them, and standards for data quality and reliability;
- Calculation methodology for each measure;
- Performance reporting formats;
- Methods for establishing plausible state-level targets or thresholds for each measure; and
- Discussion of broader deployment issues, such as any recommended phasing of the measures and deployment options, along with relative merits and risks of each option.

For the Tier 1 measures in Table 1.1, this report identifies a state-driven target-setting process which includes the following steps:

1. Standard definition of a target: A target is a specific value for a measure that an agency would like to achieve.
2. Data-based classification of performance condition: develop a performance threshold table.
3. Link performance condition to varying investment levels: develop a investment chart.
4. Select specific target levels through a collaborative process: involve agency senior staff and performance area experts, stakeholders, elected officials and the public.
5. Track progress towards achieving the targets over time and refine data collection procedures.
6. Adjust targets over time based on financial and policy changes: targets can be set for both the short term and long term.

The elements of Section 2 are intended to provide self-contained technical guides for each measure for a state DOT to calculate a measure, associated target, and report the results.

Section 3 describes current practice for Tier 2 measures, and indicates what will be needed to move them to "Tier 1". Issues include:

- Coming to consensus on measure definitions;
- Consistency in measurement; and

- Available resources.

Section 4 describes the next steps for "Tier 3" measures.

Table 1.1 Recommended Tiered Measures

Goal Area	Tier 1 – Ready for Deployment	Tier 2 – Additional Development Required	Tier 3 – Proposal Stage
Safety	• 5 year moving average of the state number of fatalities	• 5 year moving average of the state number of serious injuries	
Pavement Preservation	• IRI on NHS	• Structural adequacy on NHS	
Bridge Preservation	• Deck area of structurally deficient bridges on NHS		• Structural adequacy of NHS bridges
Congestion/ Operations		• Travel time-based metric • Congestion cost • Reliability on the Interstate system	• Incident Management on NHS Routes – Response time – Clearance time • Work zone closure
Environment		• GHG emissions	• Stormwater runoff
Freight/Economic Competitiveness	• Speed/travel time on freight corridors • Reliability on freight corridors		• Rural highway accessibility
Livability			*Definition to be identified and draft measures proposed*
Connectivity			*TBD in Future Work*

Source: AASHTO Standing Committee on Performance Management

2.0 Tier 1 Measures

2.1 SAFETY

Five Year Moving Average of the State Number of Fatalities

Definition

The Tier 1 measure, *Five-Year Moving Average of the State Number of Fatalities*, is defined as the average annual number of fatalities over a five-year period for each state. A fatality is defined as a death of a person (motorist or non-motorist) occurring within 30 days of a crash involving a motor vehicle traveling on a roadway customarily open to the public, which is consistent with the definition used for the National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS).

Data

Fatality data from FARS will be used as the data source. The data can be obtained from the FARS Encyclopedia Web site at: http://www-fars.nhtsa.dot.gov/. The standard reporting and query facilities on this website can be used to download data for each state on total fatalities. Five-year moving averages for fatalities can be calculated in spreadsheets.

Specific FARS data elements required to calculate the Tier 1 safety measure include the following:

- Traffic fatalities (number of persons)
- Injury severity (K=fatal)
- State
- Year

Calculations

A random element occurs in the timing and location of serious crashes; therefore, the annual number of fatalities in each state may fluctuate a great deal from one year to the next. Relying on a moving average number of fatalities over a five-year period provides a more stable picture of crash occurrence in each state, and makes it easier to identify trends and establish a correlation between agency actions and observed performance. The moving average can be calculated in the following manner:

1. **Identify 5 years of fatality data.** Query data FARS database for your state, injury severity (K) equal to "fatal", and for each of the last 5 calendar years.
2. **Calculate average.** The five-year moving average can be calculated as the mean of the previous five years' fatalities:

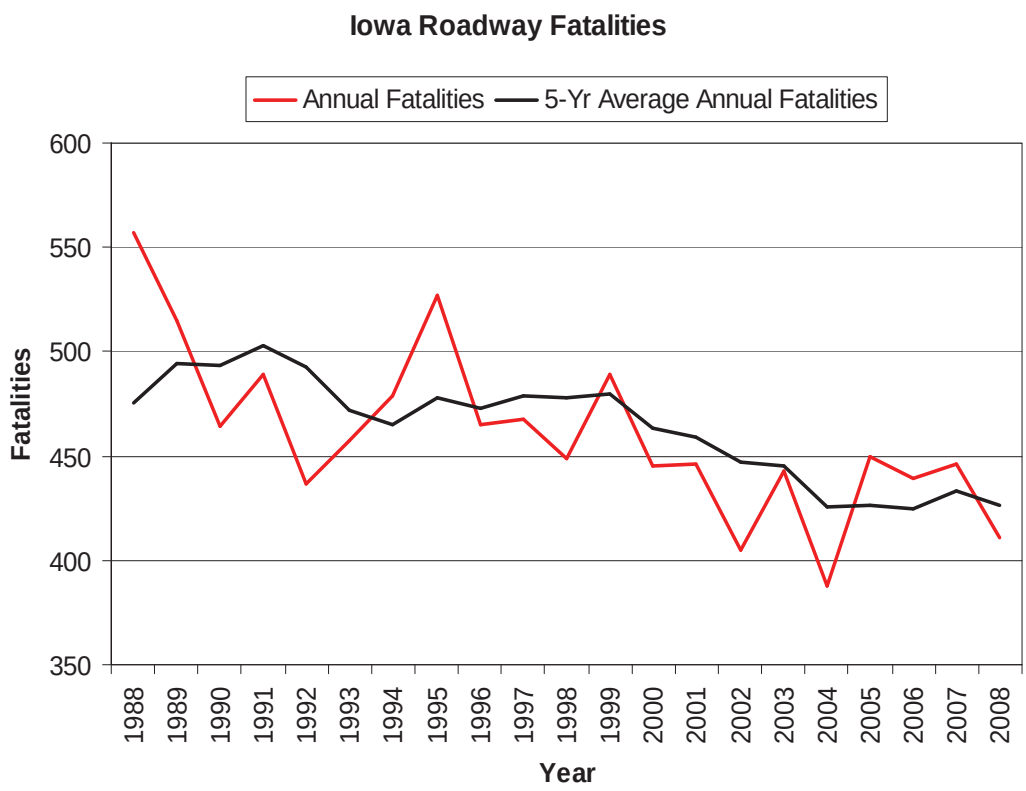
Reporting

The recommended process for reporting this measure is as follows:

1. Collect level K (fatal) injuries consistently using the standard FARS definition provided above;
2. Calculate the five year average of K fatal injuries; and
3. Report the five year average.

Figure 2.1 illustrates the sporadic ups and downs in annual fatalities in Iowa, compared to the general downward trend seen in the plot of the five-year average annual fatalities.

Figure 2.1 Iowa Roadway Fatalities



Methods for Establishing Targets

In 2007 AASHTO along with several partners established a goal to reduce fatalities by 50 percent by 2030. In addition, a more recent national initiative led by AASHTO and its partners encourages states to adopt a "zero goal", i.e., zero fatalities. Several national initiatives are being implemented to support adoption of this goal. Increasingly states are considering and/or adopting the zero goal and using the 50 percent goal as an interim measure.

The 50 percent reduction goal will require an average annual reduction at the national level of about 1,000 fatalities each year. Progress towards this goal has been made every year since 2007. According to NHTSA, early estimates for 2010 point toward a further nine percent reduction in fatalities.

Other than the zero or 50 percent policy-based goals, states use various methods for establishing targets, e.g. a ten percent reduction in fatalities. In most cases, these are policy targets as well.

Methods and tools for predicting levels of safety, given changing conditions such as population, economy, congestion, and others, are limited, although at least one tool (PlanSafe) is being pilot tested.

Tools such as the safety performance functions and crash modification factors in the recently published Highway Safety Manual (HSM) are designed to estimate crashes and determine the impact of implementing specific countermeasures on certain types of facilities, but these are just now being deployed. Some states may take a number of years to implement the HSM because data may need to be collected and staff may need to be trained. Also, the HSM was developed to increase the scientific aspects of highway safety estimation, and only a limited number of research studies meet the standards set by the HSM.[1] Furthermore, the science is young regarding behavioral countermeasures, and little information regarding benefit-cost is available. Since crashes are random and typically involve more than one variable, it is not always a simple task to determine which countermeasure or set of countermeasures would have the greatest impact on crash reduction.

Very little is known about the costs of comprehensive safety solutions, even in instances where it might be possible to estimate the outcome or impact. Therefore, tying funding to potential safety targets is not a current practice.

NCHRP 20-24(37)C recommended state practices for setting performance targets and continuous monitoring, such as:

- States would benefit from adoption of a unifying message for all agencies with a highway safety mission. The target itself may provide a "unifying

[1] The Crash Modification Clearinghouse and the HSM contain information related to this issue.

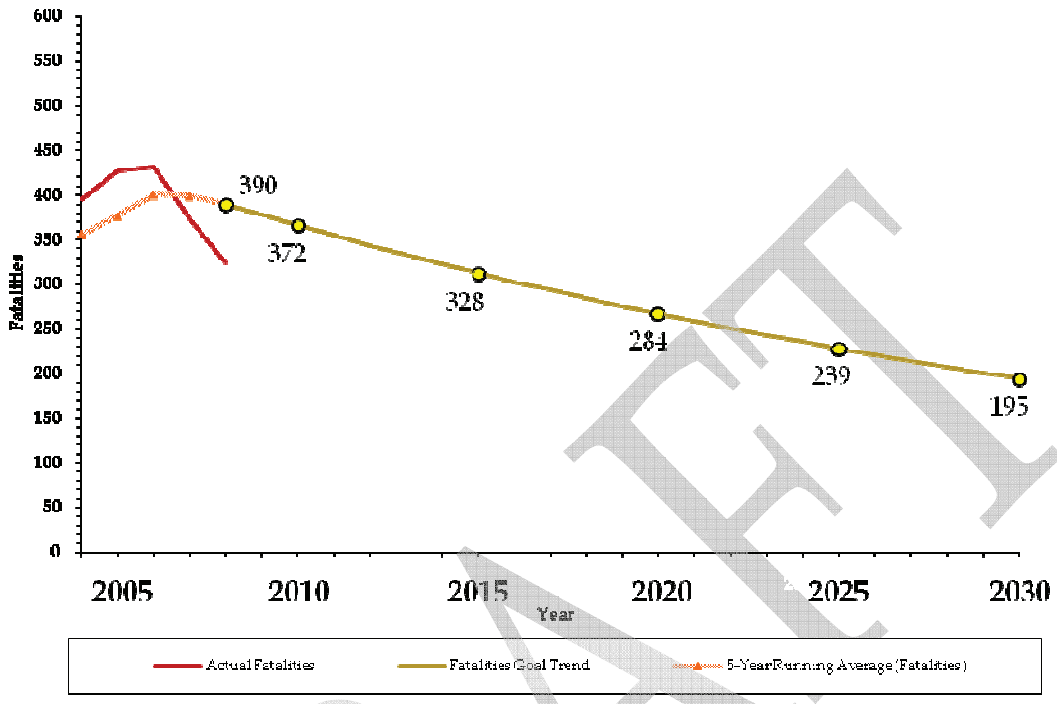
message" for all agencies and individuals involved. Setting the target would result in agreement on a "mantra" or theme (e.g., "Towards Zero Deaths" or "Zero Fatalities") and branding of all safety programs and safety-related messaging. This action promotes the understanding that everyone is working towards a common goal, collaboration across agencies is essential for success, and a multidisciplinary, multi-faceted approach is required.

- Set targets through strategic safety planning processes and actively monitor progress. Continually share performance results among the major safety partners with frequent updates.
- Improve dissemination of crash data by making it accessible on the Internet and publishing or distributing crash maps by type, while at the same time taking steps to ensure the practice does not increase the state's liability.

For the Tier 1 fatality measure, states can use the targets proposed by AASHTO and its safety partners. As noted above, the 2007 AASHTO goal is to reduce fatalities by half by 2030. States may establish a trend line beginning with the five-year average of 2005-2009 and extend it to show the 2030 target, e.g. half of the five-year average. The trend line also establishes interim goals, such as 2015 or 2020[2] (Figure 2.2).

[2] A straight linear assumption to set annual targets may be simplistic, especially since infrastructure improvements take some time to implement but may provide benefit over the life of the project (on average at least 10 years). We might expect greater reductions in the out years. However, infrastructure projects designed to improve safety performance are rarely standalone efforts. Parsing out the expected effect of a single countermeasure may not reflect reality.

Figure 2.2 Nevada Fatality Milestones and Goals through 2030



As more is known about the cost of comprehensive safety solutions and their impacts on fatalities, states may want to revisit the fatality target using the following steps:

4. Standard definition of a target: A target is a specific value for a measure that an agency would like to achieve.
5. Data-based classification of performance condition: develop a performance threshold table.
6. Link performance condition to varying investment levels: develop a investment chart.
7. Select specific target levels through a collaborative process: involve agency senior staff and performance area experts, stakeholders, elected officials and the public.
8. Track progress towards achieving the targets over time and refine data collection procedures.
9. Adjust targets over time based on financial and policy changes: targets can be set for both the short term and long term.

Examples of how this process can be deployed in practice are shown in the other Tier 1 measure sections that follow.

Deployment Issues

FARS data are the most complete and accurate fatal crash data available. Deployment issues should not be problematic. According to the NHTSA's Center for Statistics and Analysis (Federal view) and Louisiana State University (state view), no serious issues are associated with the quality and accessibility of FARS data. A handful of fatalities may not be reported each year but those incidences are rare. Also, when using data from the most recent five years of "closed" FARS files, the earliest files are closed and will not change. However, the final year can be adjusted with new data until the next year's file is closed; therefore, the most recent file may change slightly over the year, which provides additional evidence of the usefulness of multiple years of crash data. Again, the changes are minimal. The only potential data issue concerns timeliness. In general, the FARS file becomes available several months after the end of the calendar year. In other words, the 2010 FARS file can be expected about August of 2011.

2.2 PAVEMENT PRESERVATION

International Roughness Index (IRI) on NHS

Definition

The proposed measure is the percent of lane-miles on the NHS classified as "good", "fair", and "poor", as determined by thresholds for the International Roughness Index (IRI). AASHTO PP 37 *Standard Practice for Determination of International Roughness Index (IRI) to Quantify Roughness of Pavements* defines the International Roughness Index (IRI) as "a statistic used to estimate the amount of roughness in a measured longitudinal profile." This measure is first calculated by determining the value of IRI for all roads on the NHS. Using thresholds as defined by FHWA, identify the lane-miles classified as "good" (IRI < 95), "fair" (IRI between 95 and 170), and "poor" (IRI > 170), and divide by total lane-miles to get the percent of pavement within each category.

IRI is widely recognized as an indicator of road smoothness and a key measure of pavement functional performance and customer satisfaction. State agencies are required to report IRI to the Highway Performance Monitoring System (HPMS) for the full extent of the National Highway System (NHS) roadways[3]. Furthermore, the State agencies typically collect and store IRI data in their Pavement Management System (PMS) databases for decision making on project priority, funding and program development.

[3] Highway Performance Monitoring System (HPMS) Field Manual, Appendix E, Office of Highway Policy Information, Federal Highway Administration, 2005.

In developing a framework for calculating and reporting IRI values for pavement management across the U.S., the following key issues were considered:

- The framework will potentially be applied by a wide variety of users (Federal, State, and local highway agencies across the nation).
- Pavement profile measurement systems for the wide variety of users are not the same and could be significantly different from agency to agency.
- Profile data reduction and IRI estimation methodology for the wide variety of users are not the same and could be significantly different from agency to agency.

Recognizing these differences in practice, there have been several initiatives to harmonize and standardize profile measurement and IRI estimation procedures. AASHTO, ASTM, and other agencies have published guidance for profile operators, data analysts, pavement engineers and managers. Table 2.1 provides a list of relevant ASTM and AASHTO standards for equipment certification and calibration, measurement practice, report format, and IRI computation.

FHWA requires state agencies to follow HPMS Field Manual guidelines on measuring and reporting IRI data in HPMS to ensure nationwide consistency and comparability. For network level measurements, the HPMS Field Manual refers to AASHTO R43M/R43 and ASTM E 950 standards. While other standards listed in Table 2.1 are related to project-level measurements, they contribute to consistency at the network level. Thus, the HPMS guidance is an important step to achieve standardization and consistency in measuring and reporting IRI data.

While the highway agencies continue to adapt to HPMS requirements, the proposed framework is designed with sufficient flexibility to ensure that it is applicable to the different procedures already in practice and will be suitable for use even after the current systems in place are harmonized. An important aspect of this approach is that it is flexible and allows all highway agencies to contribute data without fundamentally changing their business practices (i.e., IRI data collection practices and analysis methodologies) while defining thresholds (i.e., IRI values for good, fair, and poor) that are common across all agencies.

Table 2.1 List of Relevant ASTM/AASHTO Standards for IRI Measurement

Standard	Title	Purpose
AASHTO PP 37	Standard Practice for Determination of IRI to Quantify Roughness of Pavements	• Describes a method for estimating roughness for a pavement section • Proposes guidelines for a QA plan
AASHTO R56	Standard Practice for Certification of Inertial Profiling Systems	• Describes minimum performance requirements for inertial profilers • Describes a certification procedure for test equipment
AASHTO M328	Standard Equipment Specification for Inertial Profiler	• Defines the required attributes of an inertial profiling system
AASHTO MP11	Standard Equipment Specification for Inertial Profiler	• Defines attributes for inertial profilers developed for the purpose of longitudinal pavement profile measurements and IRI calculation.
AASHTO R57	Standard Practice for Operating Inertial Profilers and Evaluating Pavement Profiles	• Describes the procedure for operating and verifying the calibration of an inertial profiler.
AASHTO R54	Standard Practice for Pavement Ride Quality When Measured Using Inertial Profiling Systems	• Provides an example specification for Owner-Agencies to use in development of specific language when requiring the measurement and evaluation of ride quality and compliance using inertial profiling systems.
ASTM E 867	Terminology Relating to Vehicle-Pavement Systems	• Describes a data file format for profile measurements.
ASTM E 950	Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference	• Covers the measurement and recording of the profile of vehicular-traveled surfaces with an accelerometer established inertial reference on a profile-measuring vehicle.
ASTM E 1170	Standard Practices for Simulating Vehicular Response to Longitudinal Profiles of Traveled Surfaces	• Covers the calculation of vehicular response to longitudinal profiles of traveled surface roughness. • Presents standard vehicle simulations (quarter, half, and full car) for use in the calculations.
ASTM E 1296	Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements	• Covers the mathematical processing of longitudinal profile measurements to produce IRI
ASTM E 2560-07	Standard Specification for Data Format for Pavement Profile	• Describes a data file format for pavement profile

Data

All data required for calculating the recommended pavement measures are available in the Highway Performance Monitoring System (HPMS) file. The calculations described below are based on the following set of HPMS data items. The item numbers used throughout this section correlate to the items described in the 2005 edition of the *HPMS Field Manual*. The Field Manual was recently updated in September 2010 to reflect modifications to the HPMS program. The updated version is referred to as HPMS 2010. The corresponding HPMS 2010 fields names are provided below in italics.

Item 3	Reporting Units – Metric or English (*N/A; HPMS 2010 requires data to be submitted in English units*);
Item 6	Standard Sample (*Sample_ID*);
Item 11	LRS Beginning Point (*Begin_Point*);
Item 12	LRS Ending Point (*End_Point*);
Item 18	Generated Functional System Code (*F_System*);
Item 19	National Highway System (NHS);
Item 34	Number of Through Lanes (*Through_Lanes*);
Item 35	Measured Pavement Roughness (IRI); and
Item 49	Standard Sample Expansion Factor (*Expansion Factor*).

Further guidance on standardized methods for measuring and calculating IRI data itself for input into HPMS is discussed in "Deployment Issues" below.

Calculations

1. **Identify Standard Sample Sections.** IRI data is only required for standard sample segments. Filter out segments that DO NOT meet this criterion.

   Item 6 = 1

2. **Remove Null IRI Values.** These segments are either unpaved or are missing IRI data. Filter out segments that meet this criterion:

Item 35 = 0

3. **Calculate Length of Each Segment in Miles.** If data is in metric units, convert length to miles.

   If *Item 3* = 1, then

   $Length = \left(\frac{Item\ 11 - Item\ 12}{1.609344}\right)$

   If *Item 3* = 0, then

   Length = *Item 11* – *Item 12*

4. **Calculate Expanded Lane-Miles.**

   Expanded Lane-Miles = *Length* X *Item 34* X *Item 49*

5. **Identify NHS Segments.** Flag all segments that meet this criterion:

   Item 19 > 0

6. **Apply Thresholds.** Categorize each segment as good, fair, or poor by applying these thresholds to the IRI value in *Item 35*.

   a. If *Item 35* < 95, then the segment is "good."

   b. *If Item 35* > 170, then the segment is "bad."

   c. Otherwise the segment is "fair."

7. **Calculate Percent Good, Fair, and Poor for Each System.**

   a. Good – For all NHS segments flagged in Step 5:

   $$\left(\frac{\sum Expanded\ Lane\ Miles \text{ classified "Good"}}{\sum Expanded\ Lane\ Miles}\right) \times 100$$

   b. Fair – For all NHS segments flagged in Step 5:

   $$\left(\frac{\sum Expanded\ Lane\ Miles \text{ classified "Fair"}}{\sum Expanded\ Lane\ Miles}\right) \times 100$$

   c. Poor – For all NHS segments flagged in Step 5:

   $$\left(\frac{\sum Expanded\ Lane\ Miles \text{ classified "Poor"}}{\sum Expanded\ Lane\ Miles}\right) \times 100$$

Further explanation on measurement and calculation techniques for IRI itself are in "Deployment Issues" below.

Reporting

Table 2.2 represents a recommended template for reporting pavement condition. States report pavement data for the HPMS; these HPMS data will then be used to calculate the percent good, fair, and poor for the NHS as outlined above.

Table 2.2 Pavement Performance Measure Template

System	Percent Good	Percent Fair	Percent Poor
Total NHS			

Methods for Establishing Targets

A target is a specific value for a measure that an agency would like to achieve. The target for pavement will be expressed as the percent of pavement in good condition. The higher the target value, the better the overall condition of the network.

These targets should be fiscally-constrained. This type of analysis enables agencies to conduct scenarios analysis and answer the following types of questions:

- Is current pavement performance satisfactory? If so, how much would it cost to maintain this performance over the next 10 years?
- What would be the impact on pavement performance if the budget for the pavement program increased by 10 percent for the next 10 years?
- What budget would be required to improve pavement performance by 20 percent over the next 10 years?

The steps for selecting a specific target are as follows:

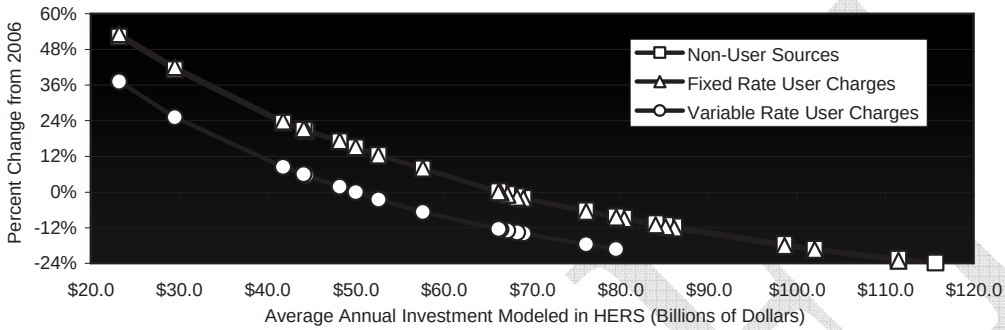
1. Develop a graph like Figure 2.3 below that illustrates the relationship between the performance measure and annual funding levels. Use this chart as the primary information piece for the process of selecting a specific pavement target. The selection of a target should be financially constrained.

   Most state DOTs use a pavement management system (PMS) that can be used to predict pavement condition over time for different funding assumptions; the Highway Economic Requirements System – State Version (HERS-ST) should be used where a state PMS is not available.

Figure 2.3 Example Relationship Between Alternative Investment Levels and Pavement Performance

Exhibit 7-12

Projected Changes in 2026 Pavement Ride Quality Compared with 2006 Levels for Different Possible Funding Levels and Financing Mechanisms



Annual Percent Change Relative to 2006	Average Annual Investment (Billions of $2006)					Percent Change in Average IRI on Roads Modeled in HERS		
	Total Capital Outlay	Spending Modeled in HERS	HERS System Rehabiliation [2] Funding Mechanism			Funding Mechanism		
			Non-User Sources	Fixed Rate User Charges	Variable Rate User Charges	Non-User Sources	Fixed Rate User Charges	Variable Rate User Charges
7.76%	*$188.9*	$115.7	$51.4			-23.8%		
7.45%	*$182.0*	$111.5	$50.0	$50.2		-22.4%	-23.1%	
6.70%	*$166.5*	$102.0	$46.2	$46.5		-19.1%	-19.4%	
6.41%	*$160.9*	$98.6	$45.0	$45.4		-17.5%	-18.1%	
5.25%	*$140.6*	$86.1	$40.2	$40.6		-11.7%	-12.2%	
5.15%	*$139.0*	$85.1	$39.8	$40.3		-11.1%	-11.8%	
5.03%	*$137.1*	$84.0	$39.4	$39.7		-10.5%	-11.2%	
4.65%	*$131.2*	$80.4	$38.0	$38.2		-8.7%	-9.1%	
4.55%	*$129.7*	$79.5	$37.7	$37.9	$46.2	-8.2%	-8.6%	-19.3%
4.17%	*$124.2*	$76.1	$36.4	$36.6	$44.7	-6.3%	-6.6%	-17.6%
3.30%	*$112.6*	$69.0	$33.6	$33.7	$41.2	-1.9%	-2.3%	-14.0%
3.21%	*$111.5*	$68.3	$33.4	$33.5	$40.9	-1.5%	-1.9%	-13.6%
3.07%	*$109.7*	$67.2	$33.1	$33.2	$40.5	-0.7%	-1.0%	-13.0%
2.96%	*$108.4*	$66.4	$32.7	$32.9	$40.1	**0.0%**	-0.2%	-12.5%
2.93%	*$108.0*	$66.2	$32.6	$32.8	$40.0	0.3%	**0.0%**	-12.5%
1.67%	*$94.0*	$57.6	$28.7	$28.8	$35.7	7.9%	7.9%	-6.7%
0.83%	*$85.9*	$52.6	$26.4	$26.5	$33.0	12.5%	12.4%	-2.6%
0.34%	*$81.5*	$50.0	$25.2	$25.3	$31.5	15.0%	15.1%	**0.0%**
0.00%	*$78.7*	$48.2	$24.5	$24.5	$30.6	17.0%	17.1%	1.8%
-0.78%	*$72.5*	$44.4	$23.0	$23.0	$28.5	20.4%	20.8%	5.7%
-0.86%	*$71.9*	$44.1	$22.8	$22.8	$28.3	20.8%	21.2%	6.0%
-1.37%	*$68.3*	$41.8	$21.8	$21.8	$27.1	23.3%	23.8%	8.4%
-4.95%	*$48.2*	$29.5	$15.7	$15.6	$19.9	41.3%	42.0%	25.2%
-7.64%	*$37.9*	$23.2	$12.7	$12.7	$16.0	52.3%	53.1%	37.1%

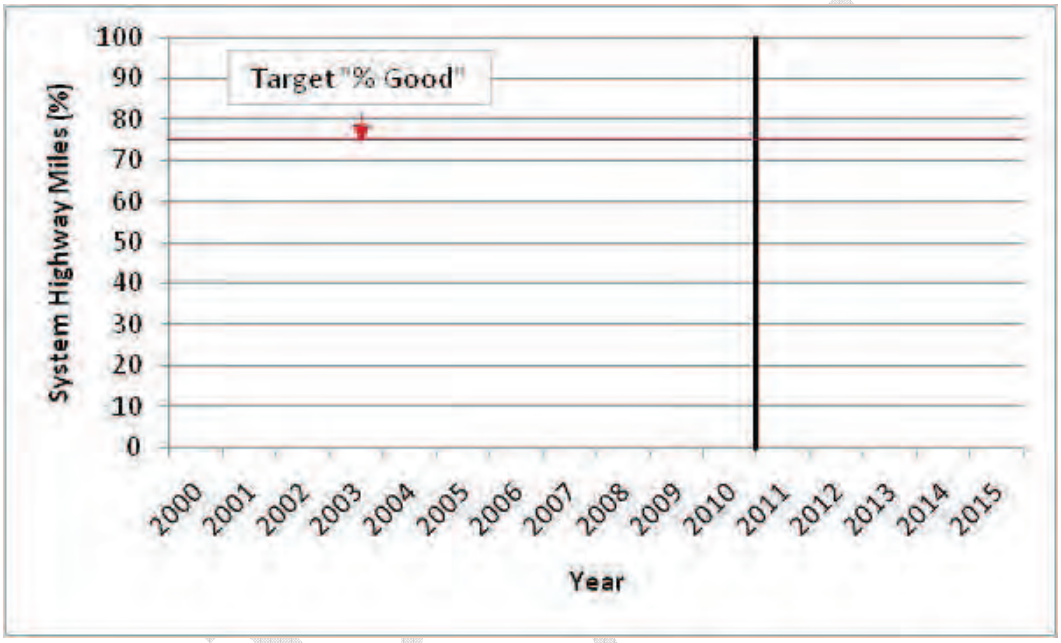
1 The amounts shown represent the average annual investment over 20 years that would occur if annual investment grows by the percentage shown in each row in constant dollar terms.

2 The amounts shown represent the portion of spending that HERS directed towards system rehabilitation rather than system expansion, which varies depending on the funding mechanism.

Source: Highway Economic Requirements System.

2. Develop a simplified chart like Figure 2.4 below and populate with actual data for the percentage of highways in good condition over time. Use this chart as the primary information piece for the process of selecting a specific target.

Figure 2.4 State-Specific Pavement Condition Trends



3. Select specific target levels through a collaborative process involving agency senior staff and performance area experts, stakeholders, elected officials and the public, considering what is achievable under different funding scenarios.
4. Track progress towards achieving the targets over time and refine data collection procedures.
5. Adjust targets over time based on financial and policy changes. Targets can be set for both the short term and the long term.

Deployment Issues

The IRI data is available for a major portion of the nation's highways through HPMS and state PMS databases. However, as indicated in the questionnaire survey results of NCHRP project 20-24(37B), there are apparent differences in the measurement and operational practices among state agencies. These differences add bias and uncertainty to the process. The lack of standards to ensure uniformity, consistency and comparability of data from various states is seen a major issue in deploying IRI as a nationwide performance measure for pavements.

Recent efforts to standardize the practices through AASHTO and ASTM standards and HPMS Field Manual will vastly improve the consistency of IRI

measurements. The following activities addressed by AASHTO standards and HPMS guidelines will help to harmonize the differences among states' practices due to equipment characteristics and operational practices:

- Protocols for profile measurements such as recommended recording interval, cut-off value for wavelengths.
- Calibration and periodic system checks.
- Minimum performance requirements for inertial profilers.
- Quality checks and quality assurance:
  - Agency-level quality assurance programs that include survey personnel certification training records, accuracy of equipment, daily quality control (QC) procedures, and periodic and on-going QC activities.
  - Automatic real-time quality checks by profiler systems.
  - Comparison of current year data sets with previous year data sets.
  - Use of verification sections.
- Certification and training for operators.
- Verification of results from any custom-built software with ProVAL.

However, there are still gaps in harmonizing the agency practices yet to be resolved such as the lack of uniform reporting standards, the bias in profile measurements due to improper measurement conditions and protocols. Focused training in this area will help in deployment of this performance measure.

When the current guidelines fail to achieve the desired consistency in existing practices, it is important to ensure harmony in the manner the national standards (i.e. thresholds and targets) are applied at the local level. This can be done by using agency-specific transfer functions to relate agency IRI measures to FHWA HPMS IRI and assigning FHWA HPMS dimensionless scale to local IRI measurements after all needed transformations have been applied. The advantage of this approach is the agency does not need to change any of its business practices and still can report to the national scale (i.e., the good, fair, poor thresholds defined above) accurately, while eliminating the need for any additional data collection.

<u>Definition and Standards for IRI</u>

AASHTO PP 37 defines the International Roughness Index (IRI) as "a statistic used to estimate the amount of roughness in a measured longitudinal profile." ASTM E 867 defines the IRI as "an index computed from a longitudinal profile measurement using a quarter-car simulation at a simulation speed of 50 mph."

Technically, the IRI is a mathematical representation of the accumulated suspension stroke of a simulated vehicle motion normalized to the distance traveled by the vehicle during a test. It is defined as the property of a roadway

longitudinal road profile. The scale starts at zero for a road with no roughness and increases proportionally with increase in road roughness.

The reporting practices of profile measurements obtained from the profiler devices are standardized. ASTM Standard E 2560 – 07 describes a data file format for profile measurements. The metadata of the file allows the user to access information such as profiler information, location, history, measurement units, pavement type, speed, temperature and climatic regions.

The raw data needed for IRI is the longitudinal surface profile of a single wheelpath of a given roadway segment. The profile must be represented as a series of elevation values taken at constant intervals along the wheelpath. Such profiles are measured for both wheelpaths.

AASHTO PP 37 outlines the provisional standards for measuring longitudinal profile and calculating the IRI for pavement sections. It specifies profile measurements on both wheelpaths, computation of IRI at 0.1 mile intervals and averaging of IRIs calculated from each of the two wheelpaths. The standard also emphasizes the need for an agency-level quality assurance (QA) plan covering certification and training, equipment calibration, verification sections, and data quality checks.

The profile measurements needed for IRI can be obtained from profiling devices. Such devices operate over a range of speeds—from static to highway traffic speeds. The longitudinal profiles are collected for various purposes such as construction quality control, acceptance testing, warranty provisions, condition assessment at project level, or network level assessment of roadway performance. Depending on the purpose, numerous equipment types are in use today. Examples include profilograph, dipstick, Response-Type Road Roughness Measuring System (RTRRMS), light-weight profiling devices, portable laser profiling systems and high-speed inertial systems.

For network level applications, high-speed inertial profiling systems are commonly employed. There are several vendors/makes of inertial profiling systems in the market. These systems may have configurations differences, such as sensor type, height and spacing, and accelerator type and positioning that may impact the consistency of measurements. Recognizing these differences in equipment characteristics, AASHTO MP 11 outlines required attributes and functionalities for inertial profilers developed for the purpose of longitudinal pavement profile measurements and IRI calculation.

The quality of profile measurements greatly influences the validity of the computed IRI. In order to obtain valid profiles, the measurements should be made at specific intervals and at sufficient resolution. NCHRP project 10-47 identified a list of factors that contributed to common profile measurement

problems[4]. Several factors, such as the variations in equipment characteristics, computational approach, roadway conditions, measurement environment, operational practices and the operator itself, were found to be causing errors and discrepancies among measured profiles. These issues confound with the repeatability and reproducibility of measurements causing inconsistencies that limit any meaningful or comparative analyses of IRI data collected by various states. These quality issues were further compounded by the lack of standardized measurement practices and data gaps.

To harmonize the differences in practices and improve measurement quality, AASHTO, ASTM and other agencies have published guidance for profile operators, data analysts, pavement engineers and managers. Key guidance documents include:

- AASHTO and ASTM standards for equipment certification and calibration, measurement practice, report format and IRI computation.
- FHWA guidance for state agencies on measuring and reporting the IRI data in the pre-2010 HPMS Field Manual, Appendix E.

These standards strive to minimize the differences in equipment characteristics and operational practices. NCHRP Research Digest 244 "Operational Guidelines for Longitudinal Pavement Profile Measurements" provides "best practices" guidance on how and when to control the factors influencing the quality of profile measurements[5].

<u>IRI Computations</u>

The longitudinal profile measurements obtained from the profiling devices are transformed mathematically in the IRI computation[6]. The methodology of IRI computation is discussed as follows:

1. The profile measurements obtained from high-speed profiler systems are first filtered, typically using a moving average filter, to remove the road grade and very long undulations. The filtering process is performed to eliminate both long and short wavelengths outside a specific bandwidth. While the long wavelengths (greater than 300 ft) are eliminated during the data collection process in accordance with AASHTO PP 37 requirements, the

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[4] Karamihas, S.M. et al, *Guidelines for Longitudinal Pavement Profile Measurements*, NCHRP Report 434, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C, 1999.

[5] Karamihas, S.M. et al, *Operational Guidelines for Longitudinal Pavement Profile Measurement*, NCHRP Research Results Digest 244, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C, 1999.

[6] Sayers, M.W. "On the calculation of international roughness index from longitudinal road profile," Transportation Research Record No.1501, Journal of Transportation Research Board, Washington, D.C. 1995.

moving average filter eliminates short wavelength through the averaging process. The profile also undergoes a series of mathematical transformations to smooth the profiles.

2. The filtered profile is processed with a quarter-car simulation at a simulated traveling speed of 50 mph. The quarter-car model implies the suspension of one corner (a quarter) of a car that simulates a response behavior typical of most kind of vehicles on the roadway[7]. The accumulation of simulated suspension motion is measured..
3. The accumulations are then summed up and normalized by the length of the profile or the roadway segment to calculate IRI.
4. When the profiles are measured simultaneously for both traveled wheel tracks, the IRI values are calculated for each single profile, and averaged to determine the mean IRI (MRI).

A paper published in the 1995 Journal of Transportation Research Board (No. 1501) titled "*On the Calculation of IRI from Longitudinal Road Profile*" serves a source document that includes theoretical basis of the algorithm in detail and how it works.

As the IRI computation involves in-depth application of mathematical concepts and data processing techniques, it is usually performed using computer programs. The source codes of computer subroutines involved in the computation process and software programs for analyzing longitudinal profiles are available in public domain[8]. Notable applications include ProVAL (Profile Viewing and AnaLysis)[9] and RoadRuf, both developed by the FHWA. These applications allow the users to view pavement profiles, analyze them and compute IRI. These applications can also be used as a reference to verify the IRI calculations of any custom-built programs. Furthermore, the practice of IRI computation has been standardized. ASTM E 1296 and AASHTO PP 37 standards provide guidance on the computation of IRI.

[7] Sayers, M.W. and S.M.Karamihas, The Little Book of Profiling, The University of Michigan, Ann Arbor, 1998.

[8] Sayers, M.W. and S.M.Karamihas, Interpretation of Road Roughness Profile Data, Report No. UMTRI 96-19, Prepared for the Federal Highway Administration, 1996.

[9] Road Profile: http://www.roadprofile.com

2.3 BRIDGE PRESERVATION

Deck Area of Structurally Deficient Bridges on the NHS

Definition

This measure is defined as the sum of the deck area of a state's NHS bridges flagged as Structurally Deficient (SD) in the National Bridge Inventory (NBI) divided by the deck area of all of a state's NHS bridges, expressed as a percent.

SD status is determined by the FHWA based on National Bridge Inventory data submitted by state DOTs. A bridge is classified as SD if:

- The condition of its deck, superstructure, substructure, and/or culvert is rated 4 or less (on a ten-point scale), OR
- Its structural condition or waterway adequacy is rated 2 or less.[10]

Data

All data items required for this measure are available in the NBI file that has been processed by the FHWA. The following variables are required:

Area	deck area
Item 5A	NBI item indicating record type
Item 32	NBI item indicating approach roadway width
Item 42A	NBI item indicating type of service on bridge
Item 49	NBI item indicating structure length
Item 52	NBI item indicating deck width
Item 58	NBI item indicating deck condition
Item 59	NBI item indicating superstructure condition
Item 60	NBI item indicating substructure condition
Item 62	NBI item indicating culvert condition
Item 67	NBI item indicating structure evaluation rating calculated by FHWA
Item 71	NBI item indicating waterway adequacy
Item 104	NBI item indicating highway system of the inventory route

[10] FHWA Non-regulatory supplement for 23 CFR 650.409, http://www.fhwa.dot.gov/legsregs/directives/fapg/0650dsup.htm

Item 112	NBI item indicating bridge length
SD	SD status: 1 = SD, null = not SD. Initially, set to null.

Calculations

1. **Remove non-bridges.** Remove all structure records that DO NOT meet the following criteria:

   Item 5A = 1

   AND

   Item 42A = 1, 4, 5, 6, 7 or 8

   AND

   Item 49 ≥ 6.1

   AND

   Item 112 = Y

   These criteria are used to identify structures that meet the definition of a "bridge" for the purposes of the NBI standards.

2. **Identify bridges that are not on the NHS.** Remove all structure records that DO NOT meet the following criterion:

   Item 104 = 1

3. **Identify SD bridges.** Flag all bridges that meet the SD criteria, as follows:

   Create a field called *SD,* with all null values

   Set *SD* = 1 if

   Item 58 < 5

   OR

   Item 59 < 5

   OR

   Item 60 < 5

   OR

   Item 62 < 5

   OR

   Item 67 < 3

   OR

Item 71 < *3*

4. **Calculate deck area.** Calculate deck area in square meters for each NHS bridge, as follows:

   If *Item 52* > 0
   then *area* = *Item 49* x *Item 52*

   If *Item 52* = 0
   then *area* = *Item 49* x *Item 32*

5. **Calculate measure.** Divide the deck area of NHS bridges flagged as SD by the total deck are of NHS bridges, as follows (the result is expressed as a percent):

$$\left(\frac{\sum area\ of\ bridges\ with\ SD=1}{\sum area}\right) \times 100$$

Reporting

The recommended process for calculating this measure is as follows:

1. Each state DOT conducts NBI inspections, compiles the results, and submits and NBI file to the FHWA (this step is currently done);
2. FHWA processes the NBI files, determines SD status for each bridge, and updates the NBI files (this step is currently done);
3. The measure is calculated for each state using the processed NBI file, as described above; and
4. Report a single number for the bridge measure for each state.

Methods for Establishing Targets

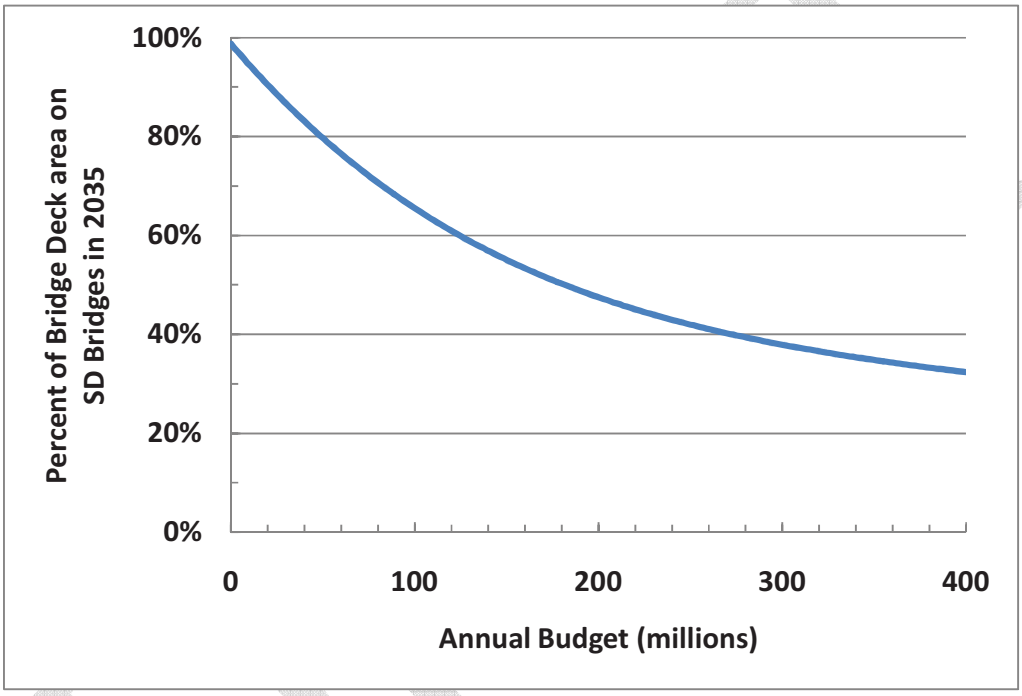
A target is a specific value for a measure that an agency would like to achieve. The target for bridges will be expressed as a percent. Given that the bridge measure is oriented around bridges that are determined to be SD, the lower the target value, the better the overall condition of the bridge network.

The steps for selecting a specific target are as follows:

1. Develop a chart like Figure 2.5 below that illustrates the relationship between the performance measure and annual funding levels. This graph shows the relationship between annual budget and resulting performance in the year 2035. For example, it indicates that if no money were spent on bridges, 100 percent of the network would be SD in 2035. Conversely, if the annual budget was $400 million, 35 percent of the network, weighed by bridge deck area, would be SD in 2035. Use this chart as the primary information piece for the process of selecting a specific bridge target. The selection of a target should be financially constrained.

Most state DOTs use the Pontis bridge management system. This tool, which is supported by AASHTO, is recommended for generating this graph. For states without Pontis, this analysis can also be performed with the National Bridge Investment System (NBIAS), although care should be taken to understand the caveats of future performance projections. The FHWA uses NBIAS to analyze the performance of bridges throughout the U.S. NBIAS relies solely on data in the NBI data file.

Figure 2.5 Example Relationship between Bridge Performance and Funding



2. Select specific target levels through a collaborative process involving agency senior staff and performance area experts, stakeholders, elected officials and the public. Targets can be set for both the short term and the long term.
3. Track progress towards achieving the targets over time and refine data collection procedures.
4. Adjust targets over time based on financial and policy changes.

Deployment Issues

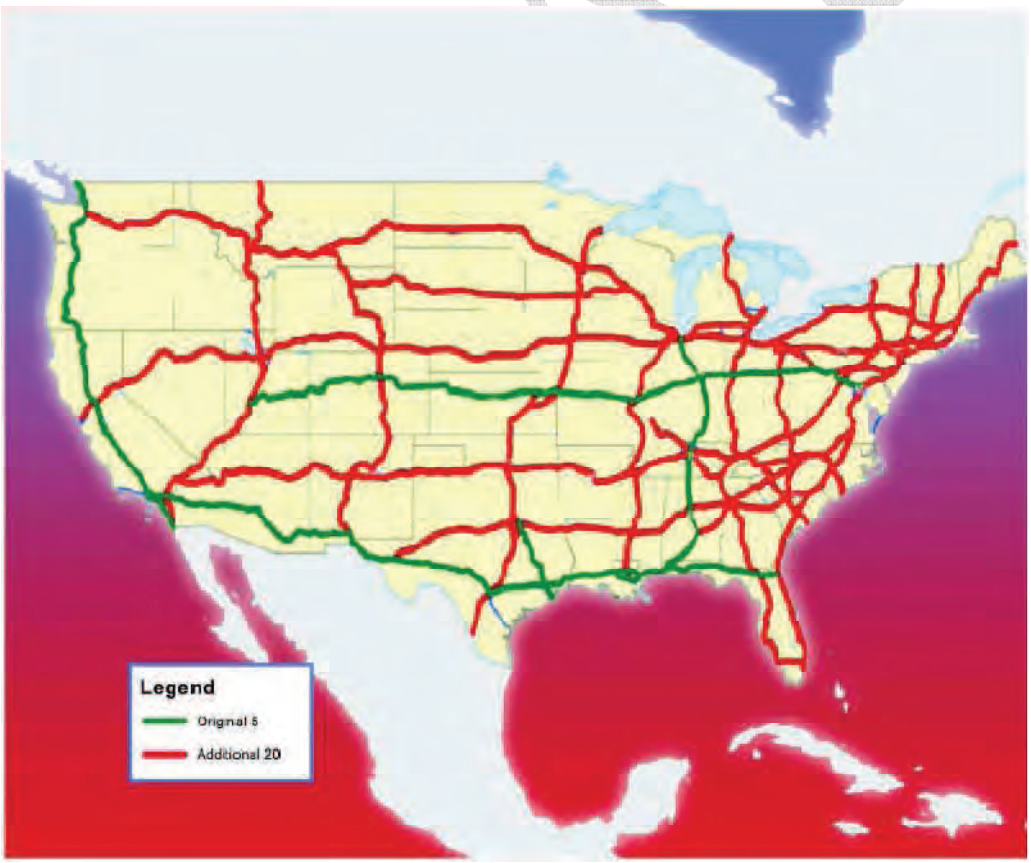
It is anticipated that the calculation and reporting of this measure in a consistent manner nationally will be straight forward because the data standards, collection procedures, quality control processes, and calculation methods are well established and have been used by state DOTs and the FHWA for several years. To improve data consistency even further it is recommended that FHWA and AASHTO continue to support bridge inspector training and quality assurance

efforts. The main challenge related to deploying this measure will be the establishment of state-specific, fiscally constrained performance targets. While the data and tools required to develop realistic bridge targets exist, few state DOTs have experience using them for forward-looking scenario analysis than for using them to report on current performance.

2.4 FREIGHT/ECONOMIC COMPETITIVENESS

The FHWA has utilized a corridor approach to track freight performance. To demonstrate this methodology FHWA used data from their Freight Analysis Framework to pick 25 corridors that have freight volumes sufficient enough to measure performance. The corridor approach presents a sound basis for identifying national and State freight performance measures. The two Tier 1 measures below present dimensions of travel on this Freight Corridor network. Figure 2.6 presents the network.

Figure 2.6 Freight Corridors on Which Performance is Currently Being Measured



Source: FHWA

In particular, the freight community, including shippers, is most concerned with traffic "lanes": corridors between major freight origins and destinations that are not segmented by state. These could include city pairs, ports to cities, or traffic lanes for major commodities moving from "resource area" origins to manufacturing or processing destinations. Performance within a traffic "lane" supports the performance of a supply chain or a distribution network and that, in turn, supports the economic productivity and competitiveness of an industry.

FHWA has identified a preliminary, draft set of such origin-destination (O/D) pairs that generally have the highest truck volumes and serve combinations of city pairs with the largest tonnages of freight:

- Interstate 5 and Route 99 in California between Sacramento and the Bay Area to the north and San Diego to the south;
- Interstate 35 between Dallas and San Antonio in Texas;
- Interstate 40 between Little Rock, Arkansas and Nashville, Tennessee;
- Interstate 65 between Chicago, Illinois and Nashville, Tennessee and between Nashville and Mobile, Alabama;
- Interstate 81 between Harrisburg, Pennsylvania and Knoxville, Tennessee; and
- Interstate 95 and the New Jersey Turnpike between New York City and Washington, D.C.

This preliminary list is not exhaustive, and other traffic lane O/D pairs could be added. These

Speed/Travel Time on Freight Corridors

Definition

The proposed measure is the average speed or travel time along a section of one or more Freight Corridors. There are three different considerations of the measure:

- At the individual Freight Corridor level, the proposed performance measure is the average speed (24-hour day) of the entire corridor.
- At the state level, the proposed performance measure is the average speed (24-hour day) of each Freight Corridor crossing the state.
- At the national level, the proposed performance measure is the average speed (24-hour day) of the entire Freight Corridor network.
- At the traffic "lanes" level, between major freight origins and destinations that are not segmented by state, this measure is the average travel time (24-hour day).

Data

To calculate this measure, the following items are required:

- A definition of the highway network on each Freight Corridor;
- A sample of trucks traveling on each section of the highway network; and
- For each truck in the sample, the travel time and speed at that portion of the network.

Definition of Highway Network

The highway network for a Freight Corridor must be divided into segments. Current research in this field typically identifies the highway network segments as contiguous lengths between 3 and 12 miles long, with length generally corresponding to two factors: homogeneity of the segment as well as the ability to obtain a suitable volume of sample data.

Truck Sample

A sample of trucks must be obtained in a manner allowing for calculation on a 24/7/365 basis. Therefore, automated approaches must be considered. Trucks must be identified which contain vehicle probe equipment, so that the vehicle may be observed. Note that an individual truck may be used in multiple highway samples, but it is not required that the truck travel the entire corridor.

A truck sample approach exists in the work that the FHWA is conducting in partnership with the American Transportation Research Institute (ATRI). The result of the research is a dataset that contains truck travel times in freight corridors, and is available in the web-based FPMweb database and reporting tool.

Single Truck Network Speed Estimate

Once trucks have been identified, one must then capture the speed at which the truck is traveling. The method used in the approach for the FPMweb tool mentioned above calculates the operational travel speed for a truck that crosses a given distance in the following steps:

1. Two positions from a unique truck are identified and checked for quality control criteria.
2. The two positions are snapped to a GIS layer to determine the physical distance traveled by the truck.
3. The time between the two positions is calculated.
4. A time/distance calculation results in an operational speed measure.

If all segments are of a similar length, it would simplify the calculations required as well as make the comparisons between segments more straight-forward. The current sources of data, however, do not utilize a standard segment length, and we account for that fact in the remaining calculations.

Truck Speed Estimate Distance

Ideally, speed estimates for each truck would be taken within every segment on which the truck travels. Operationally, this may not always be feasible. Four examples of potential reasons include:

- The frequency at which the probe technology can physically obtain information;
- The cost of obtaining each probe point of information;
- The willingness of trucks to be part of sample with more frequent probing; and
- Events which cause a temporary malfunction;

Therefore, if the two positions identified in the above calculation span multiple highway segment definitions, the same speed is assigned as a result to each segment. Given the implication of this assumption that speed is reasonably homogenous throughout the period of travel, quality assurance measures should be considered to limit the maximum distance between two probe points.

Calculations

In the calculations below, the following notational conventions are used:

- A particular highway segment found on a Freight Corridor is defined by the variable X;
- Each segment has a defined distance ($distance_x$) and an observed average speed of the sampled trucks traversing the Freight Corridor ($speed_x$);
- S is defined as the set of all Freight Corridor segments in the geographic region for which the performance measure is being calculated. As mentioned earlier, the performance measure can be calculated for a particular Freight Corridor within a state, for all Freight Corridors within a state, or for one or more Freight Corridors nationally.

The speed on the Freight Corridor(s) defined as "S" can be calculated through the following process:

1. For each segment of the Freight Corridor network, a set of trucks are observed over the entire period for which the performance measure is being reported. These data are obtained from the FHWA's FPMweb.
2. The travel time for each truck is tabulated.
3. The mean value of those tabulations is the average travel time for the segment for the period of performance measurement.
4. Once the segment-specific performance measures have been identified, the performance measure for the entire Freight Corridor is tabulated as the mean of all of the segment-specific performance measures. If the segments have

been identified to be of different distances, the mean must be weighted by the distance[11] of the segment as follows:

$$\left(\frac{\sum_{\text{for all segments "x" in corridor "S"}} \text{distance}_x \times \text{speed}_x}{\sum_{\text{all "x"}} \text{distance}_x}\right) \times 100$$

To report at a level different than the entire Freight Corridor (such as one state's Freight Corridor, the entire Freight Corridor network, or a freight traffic lane), the same calculations can be made from the relevant highway segments.

Reporting

Table 2.3 represents a recommended template for state reports of Freight Corridor speed. State agencies would report Freight Corridor speed both for the individual Freight Corridors in the state, as well as the aggregate for all Freight Corridors within the state.

Table 2.3 Freight Corridor Speed Template

	Percent with Average Speed		
Freight Corridor	**Less than 45 mph**	**Between 45-50 mph**	**Greater than 50 mph**
Freight Corridor 1			
Freight Corridor 2			
…			
ALL Freight Corridors			

Note that while the measure is identified as "speed/travel time," given the variable distances of the Freight Corridors, we recommend that states report the speed. However, for the identified freight traffic lanes (O/D pairs), average travel time can be reported.

Table 2.3 was derived from an example of how FHWA can currently report average speed on a Freight Corridor in a graphical manner by reporting information from each individual travel segment, using ATRI data. In this example as shown in Figure 2.7, from Interstate 5 in California, each segment is color coded based on the average 24-hour speed. Thresholds of 45 and 50 miles per hour were used to create three distinct categories of reporting.

Given the ability to identify the specific time at which a vehicle observation was made on a particular segment, this performance measure is well defined for the potential evolution of standards for both temporal and spatial stratification.

[11] Note that the weighting above could also be done based on the time of the segment. We have selected to weight by distance for consistency with other Tier 1 and Tier 2 performances measures for areas other than freight.

Figure 2.7 Example of Reporting of Average Speed on a Freight Corridor

Source: FHWA.

States can utilize this method of reporting at the segment level, and aggregate the travel times as described above to report the overall speed of the corridor. For internal agency use, speeds can be reported at both the 24-hour average level as well as by hour of day. Hour of day reporting can be accomplished by segmenting the data from which the calculations are made.

States may also choose to report this measure for additional subsets of the Freight Corridor within their state, such as crossing an MPO, between two MPOs, by agency regions, etc. At the sub-state level, the reporting choices are optional and left to the state agency's discretion. Major freight traffic lanes (O/D pairs), as defined above, may be multi-state. FHWA currently has data for these traffic lanes; due to this multi-state nature, it is recommended that travel times in these corridors initially be calculated by FHWA, and sent to the states impacted by these corridors for review and reporting into the AASHTO process.

While the above discussion is about "state reporting," this may in fact be better interpreted as "state specification of third-party reporting" depending on the method for acquiring the data across the entire Freight Corridor.

Calculating these values will require a significant sample size of observations for each segment. Procedures will need to be developed by FHWA in coordination with AASHTO to consider a minimum sample size for a segment, and to determine when segments may need to be consolidated to increase the total sample on the segment (even though the segment length will be longer and therefore potentially less accurate).

Methods for Establishing Targets

A target is a specific value for a measure that an agency would like to achieve. Each point depicts a data-based performance level for each measure that can be arrayed in a Performance Threshold Table. For the Freight Corridor speed goal area, the initial thresholds for the measure, defined as good, fair, and poor are illustrated in Table 2.4.

Table 2.4 Freight Corridor Speed Target-Setting Categories

Performance Category	Defined as the Percentage of Vehicles with Average Speed
Good	Above 50 mph
Fair	Between 45 and 50 mph
Poor	Below 45 mph

Note that Table 2.4 is derived from the structure of Table 2.3. As Freight Corridor speed is tracked each year, a trend line develops that can be arrayed on a chart which illustrates the impact of varying levels of investment towards improving Freight Corridor travel time. Figure 2.8 presents a *hypothetical* example of such a trend line. It is derived from Table 2.5, a template for tracking investment for an Freight Corridor.

Figure 2.8 Example of Comparing Freight Corridor Speed Performance to Investment Over Time

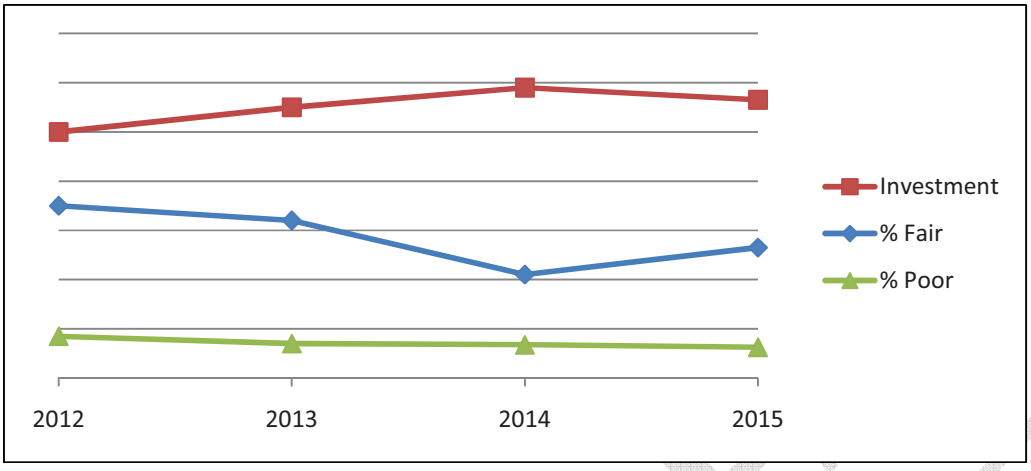


Table 2.5 Template of Tracking Speed Investment Performance for a Freight Corridor

Year	Investment	Percentage of Vehicles with Average Speed	
		Less than 45 mph	Between 45-50 mph
2012			
2013			
2014			
2015			

Once the base data outlined above is established, the steps for selecting a specific target are as follows:

- Develop a simplified chart like the example above (Figure 2.8) that illustrates the percentage of vehicles on the Freight Corridor with fair and poor speed or travel time over a number of years. Use this chart as the primary information piece for the process of selecting a specific Freight Corridor target.
- Select specific target levels through a collaborative process involving agency senior staff and performance area experts, stakeholders, elected officials and the public.
- Extend and annotate the chart to differentiate between past investment performance and intended future investment and performance.

- Track progress towards achieving the targets over time and refine data collection procedures.
- Adjust targets over time based on financial and policy changes. Targets can be set for both the short term and the long term.

Deployment Issues

Per the FHWA/ATRI research previously mentioned, a wide range of factors affect truck speed and travel-time reliability, and subsequently affect the average speed results within a corridor. Some factors that need to be considered while inspecting average speed data for performance measure use includes terrain, infrastructure design and capacity, weather, incidents, work zones, and time of travel.

From an operational perspective, there is a balance to be established between truck sample volume, truck sample distance, observation cost, and motor carrier willingness to participate. Truck sample volume should also take into account evolution in probing methodology, so that a consistent set of assumptions can be made while leveraging innovations being delivered in this technology area.

FHWA/ATRI have developed the FPMweb database and reporting tool to report on this type of information. The presence of this measure does not assume that collection or reporting must be through the FPMweb tool, but it is realistic to consider that FPMweb or a future derivative might be used to collect and report the freight measures on behalf of the states.

Below the Freight Corridor level, there is substantial value available in leveraging data at the segment level. States should have the option of utilizing segment data for other planning purposes. Similarly, states should have the option of utilizing data for multi-state corridors.

For reporting travel time by key traffic "lanes", AASHTO should begin with the pilot set identified above, but work with FHWA to refine and expand the set of these key traffic "lanes" from among the freight corridors along which FHWA/ATRI currently collect data; AASHTO can also refine the process for defining responsibility for reporting multi-state corridors using FHWA/ATRI data.

Reliability on Freight Corridors

Definition

The proposed measure is calculated as the amount of time, expressed as a percentage, that has to be added to average travel time to be "on time" for 95 percent of trips made in a corridor. Such a classification of measure is often referred to as a "buffer index."

If average travel time is one hour and the buffer index is 50 percent, a traveler would need to allow one and a half hours for the trip to be 95 percent confident

of arriving on time. To calculate the buffer index, the length of each corridor is divided by the average speed on that corridor (from the freight speed measure) to obtain the average travel time. Speed data are then used to calculate how much travel time is required to ensure that 95 percent of the trips on the corridor will be on time. Subtracting the average travel time from the 95th percentile travel time and dividing the result by the average travel time expresses the percent of time above the average a traveler needs to allow on that corridor. Like the freight speed measure, this measure is calculated both for entire Freight Corridors (crossing multiple states) and Freight Corridors within a state. At the national level, this performance measure is the distance-weighted average of all Freight Corridor buffer indices.

Data

The following data are identical to those utilized in the Freight Corridor Speed/Travel Time performance measure:

- Definition of Highway Network;
- Truck Sample;
- Single Truck Network Speed Estimate; and
- Truck Speed Network Distance

The new measure of data, which must be generated from the above data to ensure consistency across the pair of performance measures, is a statistical sample of multi-segment travel times.

Calculations

As with the Freight Corridor Speed/Travel Time performance measure, the following variables are defined:

- A particular highway segment found on an Freight Corridor is defined by the variable X;
- Each segment has a defined distance ($distance_x$) and an observed average speed of the sampled trucks traversing the Freight Corridor ($speed_x$);
- S is defined as the set of all Freight Corridor segments in the geographic region for which the performance measure is being calculated. As mentioned earlier, the performance measure can be calculated for a particular Freight Corridor within a state, for all Freight Corridors within a state, for one or more Freight Corridors nationally, or specified freight traffic lanes (O/D segments) within a Freight Corridor.

Several variables must be defined for the calculation of the reliability measure:

- The *Mean Trip Travel Time* is defined as M_x for segment "x", and M_s for all segments x in the Freight Corridor(s) under consideration;
- A single simulated "through trip" T which traverses all of the segments x;

- The simulated trip duration D_T of trip T;
- The set of all simulated D_T will yield a distribution with a mean and 95th percentile value;
- The derived Trip Buffer Index (I) for the Freight Corridor from that distribution.

The truck sample approach leverages the concept of sampling trucks not traveling the entire corridor. A consequence, however, is that the sample does not easily obtain observations matching closely to sub-corridors such as state boundaries.

To statistically generate a data set for any trip of a contiguous number of individual Freight Corridor segments (up to and including the entire corridor), the following procedure can be utilized using Excel or similar program:

1. Calculate an estimate of M_s by adding the time of each segment (M_x) for each Freight Corridor segment "x" along the trip.
2. Create a single simulated "through trip" T by randomly selecting one Single Truck Network Speed Estimate for each segment in the trip along the Freight Corridor.
3. For the single simulated through trip, calculate the simulated trip duration by converting each of the sampled speeds to travel times, and adding them:

   $$D_T = \sum_{for\ all\ segments\ "x"} \left(\frac{distance_x}{SampleSpeed_x}\right)$$

4. Repeat steps 2 and 3 for a very large number of samples, such as ten thousand, using a database program or a spreadsheet.

From this simulated set of trips, the overall buffer index can be calculated:

5. Sort the set of obtained simulated trip durations, and identify the *95th Percentile Simulated Trip Duration*.
6. Calculate the overall trip buffer index for the Freight Corridor or portion of the Corridor as:

   $$I = \frac{(95th\ Percentile\ Simulated\ Trip\ Duration - Mean\ Trip\ Travel\ Time)}{Mean\ Trip\ Travel\ Time}$$

<u>Segment Level</u>

For each segment of the Freight Corridor network, a set of trucks are observed over the entire time period for which the performance measure is being reported. The performance measure should be calculated for the same time period as is selected for the Freight Corridor Travel Time/Speed measure. The following procedure can be performed in Excel or similar program:

1. The travel time for each truck is tabulated, and the *Mean Segment Travel Time* M_x is computed.

2. All tabulations of the travel time are then sorted from lowest to highest. The number of observations are noted, multiplied by 0.95, and rounded to the nearest integer. In Excel the formula is:

   95thPercentileObservationNumber = round(*TotalObservations* * 0.95, 0)

3. From the set of tabulations, the tabulation equal to the calculated nearest integer is identified, and that tabulation is set as the *95thPercentileSegmentTravelTime.*

4. The Buffer Index for the segment is calculated as:

$$SegmentBufferIndex = \frac{(95th\ Percentile\ Segment\ Travel\ Time - Mean\ Segment\ Travel\ Time)}{Mean\ Segment\ Travel\ Time}$$

Multi-Segment, State, or Freight Corridor-wide Level

Unfortunately, the *95thPercentileSegmentTravelTime* cannot be added across segments to get a total 95th percentile time for multiple segments. To do so would assume that at the time of the 95th percentile calculation for the corridor, all segments of the corridor are operating at an inefficient level, which is likely to be incorrect.

Instead, individual truck travel times for the multiple segments or entire corridor must be either observed or calculated. Once a set of observations of these travel times is developed, the calculations above can be repeated to get the buffer index for the entire trip.

Reporting

Table 2.6 represents a recommended template for state reports of Freight Corridor reliability. For consistency, Freight Corridor reliability should be reported using the same approaches as Freight Corridor Speed/Travel Time. Freight Corridor reliability can be reported for various levels of stratification, including at the freight traffic lane O/D level. If highly granular time stratification is desired, however, care must be taken in developing a large enough simulated trip set so that each time stratum has a sufficient number of simulated trips.

Table 2.6 Freight Corridor Reliability Template

Freight Corridor	Trip Buffer Index	95th Percentile Travel Time	Mean Travel Time
Freight Corridor 1			
Freight Corridor 2			
…			
ALL Freight Corridors			

Calculating these values will require a significant sample size of observations for each segment, as well as simulation cycles of tabulating a sample truck's movement through the segments. Procedures will need to be developed to consider a minimum sample size for a segment, and to determine when segments may need to be consolidated to increase the total sample on the segment (even though the segment length will be longer and therefore potentially less accurate).

Methods for Establishing Targets

Targets are a quantifiable point in time at which an agency achieves all or a portion of its goals. Each point depicts a data-based performance level for each measure that can be arrayed in a Performance Threshold Table. For the Freight Corridor reliability goal area, the template for the measure, defined as good, fair, and poor are illustrated in Table 2.7. The thresholds for performance levels should be determined through a collaborative process involving senior staff of participating agencies and performance area experts and other key stakeholders.

Table 2.7 Template for Freight Corridor Reliability Target-Setting Categories

Performance Category	Freight Corridor Buffer Index
Good	
Fair	
Poor	

As Freight Corridor reliability is tracked each year, a trend line develops that can be arrayed on a chart which illustrates the impact of varying levels of investment towards improving Freight Corridor reliability. Figure 2.9 presents a *hypothetical* example of such a trend line. It is derived from Table 2.8, a template for tracking investment for an Freight Corridor.

Figure 2.9 Example of Comparing Freight Corridor Reliability Performance to Investment Over Time

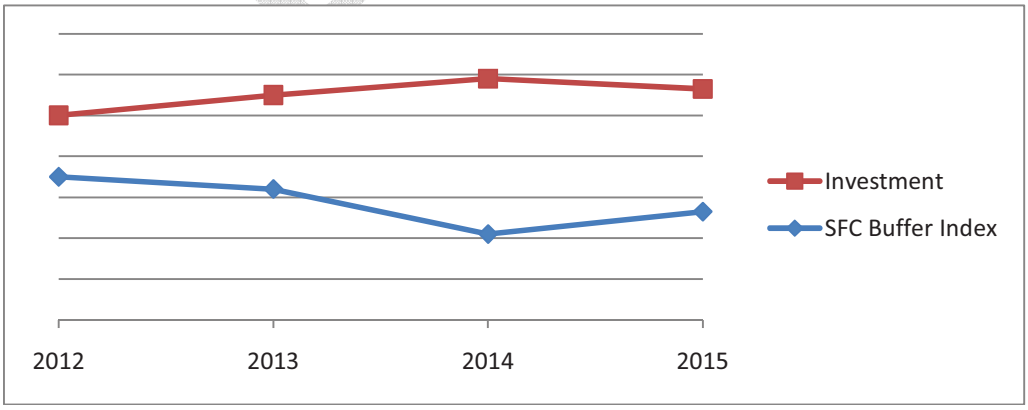


Table 2.8 Template of Tracking Reliability Investment Performance for a Freight Corridor

Year	Investment	Between 45-50 mph
2012		
2013		
2014		
2015		

Once the base data outlined above is established, the steps for selecting a specific target are as follows:

- Develop a simplified chart like the example above (Figure 2.9) that illustrates the percentage of vehicles on the Freight Corridor with fair and poor reliability over a number of years. Use this chart as the primary information piece for the process of selecting a specific Freight Corridor target.
- Select specific target levels through a collaborative process involving agency senior staff and performance area experts, stakeholders, elected officials and the public.
- Extend and annotate the chart to differentiate between past investment performance and intended future investment and performance.
- Track progress towards achieving the targets over time and refine data collection procedures.
- Adjust targets over time based on financial and policy changes. Targets can be set for both the short term and the long term.

Deployment Issues

The single-most complex deployment issue above and beyond those to be encountered for the Freight Corridor Speed/Travel Time measure is setting up a consistent approach for developing a set of simulated trips for various sub-corridor trips. Differing approaches for developing these simulations samples may yield unintended confounding effects when attempting to compare measures across Freight Corridor sub-corridors.

The issue of low sample size for individual segments, while important for the Freight Corridor Speed/Travel Time measure, is of extra concern here. Because the deployment approach will require sampling the segment data, an abnormally low number of samples for individual segments may cause artificial effects in the reliability measure. Depending on the distribution of smaller samples, the impact could either artificially inflate or deflate the performance measure results.

Similar to the Speed/Travel Time measure, for reporting reliability by key traffic "lanes", AASHTO should begin with the pilot set identified above, but work

with FHWA to refine and expand the set of these key traffic "lanes" from among the freight corridors along which FHWA/ATRI currently collect data; AASHTO can also refine the process for defining responsibility for reporting multi-state corridors using FHWA/ATRI data.

3.0 Tier 2 Measures

3.1 INTRODUCTION

Tier 2 measures meet one or two of AASHTO's performance measure criteria, defined in Section 1, and require further work before they will be ready for deployment. This section identifies each Tier 2 measure, defines each measure to the extent possible, and identifies issues that will need to be resolved to move each one to Tier 1. As some measures are currently more developed at a national level, the level of detail for each measure varies. For some formulas are well established, but data issues must be overcome; for others data sources may be consistent, but field measurement varies. Where a consistent state-of-the-practice exists, it is identified.

3.2 SAFETY

Five-Year Moving Average of the State Number of Serious Injuries

Background and Definition

The *Five-Year Moving Average of the State Number of Serious Injuries* is defined as the average annual number of serious injuries over a five-year period for each state. Fatal crashes on any given roadway segment are statistically rare events; therefore, consideration is given to measuring serious injuries as well as fatalities because crashes resulting in major injuries may result in a significant negative impact on the quality of victims' lives. Also, including serious injury data provides a better representation of the network or highway performance in comparison to other locations, so selected projects have the greatest potential for crash reduction.

The difference between a fatal crash and a serious injury crash is often the result of factors unrelated to the roadway, such as the victim's health and fitness, the vehicle type and safety features, or the timing and quality of emergency response.

American National Standards Institute (ANSI) D16 defines incapacitating injury as "any injury, other than a fatal injury, which prevents the injured person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred." It goes on to suggest inclusions:

- Severe lacerations
- Broken or distorted limbs

- Skull or chest injuries
- Abdominal injuries
- Unconsciousness at or when taken from the accident scene
- Unable to leave the accident scene without assistance
- And others

Exclusions are also specifically mentioned including:

- Momentary unconsciousness
- And others

Almost every state uses the KABCO scale to measure the functional injury level of the victim at the crash scene. The codes are selected based on the on-site judgment of the investigating police officer completing the crash report. The scale is defined as follows:

- K = Fatal injuries
- A = Incapacitating Injury
- B = Non-incapacitating Injury
- C = Possible Injury
- O = Property Damage Only
- ISU = Injury severity unknown

Specific data elements required to calculate the Tier 2 safety measure include the following:

- Injuries resulting from traffic crashes (number of persons)
- Injury severity (A=incapacitating)
- State
- Year

A random element occurs in the timing and location of serious crashes; therefore the annual number of serious injuries in each state may fluctuate from one year to the next. Relying on a moving average over a five-year period provides a more stable picture of crashes in each state and makes it easier to identify trends and establish a correlation between agency actions and observed performance.

The five-year moving average can be calculated as the mean of the number of serious injuries over the previous five years, as shown in the following equation:

$$A_{avg} = \frac{A_n + A_{n-1} + A_{n-2} + A_{n-3} + A_{n-4}}{3}$$

The number of serious injuries should be reported on a calendar year basis from January 1 to December 31.

For the Tier 2 serious injury measure, targets can be set using the proposed fatality target agreed to by AASHTO and its safety partners. The goal is to halve fatalities by 2030. States may establish a similar target with respect to serious injuries, e.g. halve serious injuries by 2030. A trend line beginning with the five year average of 2007-2009 and extending it to show the 2030 target establishes interim goals, e.g. 2015 and 2020. However, serious consideration should be given to establishing a target using the process outlined in Section 1 including the following steps as better predictive methods become available:

1. Standard definition of a target: A target is a specific value for a measure that an agency would like to achieve.
2. Data-based classification of performance condition: develop a performance threshold table.
3. Link performance condition to varying investment levels: develop a investment chart.
4. Select specific target levels through a collaborative process: involve agency senior staff and performance area experts, stakeholders, elected officials and the public.
5. Track progress towards achieving the targets over time and refine data collection procedures.
6. Adjust targets over time based on financial and policy changes: targets can be set for both the short term and long term.

Issues

The primary challenge for advancing incapacitating injuries to Tier 1 status is achieving consensus and consistency on the definition of serious injury. Police reports in almost every state use KABCO to classify crash victim level of injury. The KABCO coding scheme allows non-medically trained persons to make on-scene injury assessments without a hands-on examination. Police officer observations at a crash scene may differ dramatically from the results of a hospital trauma center or emergency room examination. KABCO ratings are imprecise and inconsistently coded within and among states and over time.

Methods and tools for predicting levels of safety given changing conditions, such as population, economy, congestion, and others, are limited, although at least one tool (PlanSafe) is being pilot tested. Tools such as the safety performance functions and crash modification factors in the recently published Highway Safety Manual are designed to estimate crashes and determine the impact of implementing specific countermeasures on certain types of facilities, but these are just being deployed. Some states may take a number of years to implement as data may need to be collected and staff may need to be trained. Also, the HSM was developed to increase the scientific aspects of highway safety estimation, and only a limited number of research studies meet the standards set by the HSM. The Crash Modification Clearinghouse and the HSM contain information

related to this issue. Further, the science is young regards to behavioral countermeasures, so little information regarding cost benefit is available. Since crashes are random and typically involve more than one variable, it is not always a simple task to determine which countermeasure would have the greatest impact on crash reduction.

Having established the difficulty of setting precise targets, it would be even more difficult to tie targets to funding since very little is known about the costs of comprehensive safety solutions even in instances where it might be possible to estimate the outcome or impact.

Process to Advance Measure

ANSI D16 provides a relatively precise definition of a level A injury. However, not all states consistently use these definitions and police accident reports may define them differently. Furthermore, to achieve true consistency, the "and others" provided in ANSI D16 would need clear parameters.

At least two approaches for improving serious injury data are available. One is to address how "serious injury" is defined and consistently deploy the KABCO methodology; the other is to identify and deploy a different metric, but this may also create challenges with definition or only act as a surrogate for crashes.

Most states have a statewide crash report. The reports would need to be standardized and all states would have to adopt the standard level A (incapacitating injury) element. This would undoubtedly require changing the reports in some states, adopting a statewide report in some states, and, in all states, ensuring all police officers who investigate crashes are appropriately trained. This process would require achieving consensus on the definition of the KABCO scale elements among all entities responsible for maintaining the state crash databases and extensive training and retraining of state and local police. However, this solution would not address the aftermath of a crash and the possibility of incorrectly identifying injury seriousness at the scene. In some cases, no injury is evident but the victim later goes to the emergency room where internal injuries are diagnosed. In others, a victim may appear to be seriously injured due to the amount of blood in evidence; yet, the injuries are later diagnosed as mild or less severe. Some level of follow up with victims reported as seriously injured would be required for the data to become more consistent and accurate.

One solution is to connect police reports to medical data, but it is a difficult process. The NHTSA Crash Outcome Data Evaluation System (CODES) attempts to establish a probabilistic matching of trauma records with crash reports, but few states are using the process and the accuracy rate for many states could be increased.

To address these issues, we recommend a process led by AASHTO, the Governors Highway Safety Association (GHSA), and the International

Association of Chiefs of Police (IACP). This process would include the following elements.

- **Leadership** – The AASHTO Standing Committee on Highway Traffic Safety (SCOHTS), the SCOHTS Safety Management Subcommittee, the Standing Committee on Performance Management, GHSA, and the IACP State and Provincial Division would jointly lead this effort. The Subcommittee includes AASHTO, GHSA, and IACP representatives and is composed of several Work Groups, two of which focus on safety data and communications. These Work Groups would form a Task Force, and with assistance and liaisons from the Standing Committees, GHSA, and IACP, coordinate the overall effort. The Task Force would define the specific tasks necessary for moving the measure to Tier I status and create a series of strategies for implementing the tasks.
- **Participation and practitioner support** – The Task Force would solicit participation from state DOTs, highway safety offices (SHSO), state police organizations, and representatives of the medical community, such as the Centers for Disease Control and Prevention, the National Association of Emergency Medical Physicians, and perhaps others. Close coordination at the Federal level with the FHWA and the National Highway Safety Administration (NHTSA) would be essential. Most states have active coalitions to support implementation of the Federally required Strategic Highway Safety Plans (SHSP). The coalitions would be helpful for implementing the statewide programs that will be necessary in many cases to move incapacitating injuries to Tier 1 status. In addition, states are required to have a multidisciplinary Traffic Records Coordinating Committee (TRCC). The TRCCs would need to integrate implementation into their existing plans and programs.
- **Measure and implement definition** – The Task Force would assess the current state of practice with regard to the methods states use to define, document, and measure incapacitating injuries. This effort would include reviewing available documentation, such as legal definitions, definitions used in police training programs, etc.; interviewing a sample of state and local police officers to obtain their impressions of how A injuries are measured; reviewing the statewide police accident report form to ensure the working definitions are consistent with the report elements; and interviewing police trainers to learn how law enforcement is trained to capture injury data. The Task Force would prepare precise recommendations on how the measure should be defined and specific action steps for implementing any necessary changes. An additional Task Force duty would be to devise a communications plan to disseminate the information and work with appropriate officials in all states to adopt the definition and implement the action steps.
- **Research** – The interviews with state and local law enforcement should be supplemented by interviews with relevant NHTSA and FHWA data

managers, TRB research and program managers, university and private sector researchers and others to establish a realistic assessment of the current state of practice and identify the most feasible and effective strategies for moving toward a standard definition and data collection methodology for obtaining consistent data on incapacitating injuries. Of special interest would be practitioners in NHTSA's National Center for Statistics and Analysis, where the FARS program is located. Their experience in developing and implementing the FARS program would be instructive for identifying effective strategies, potential barrier and solutions, and opportunities for success. As states implement these measures, the Task Force should continually track and assess state experience, and recommend refinements to the process, as well as additional policies, resources, and tools that may be needed to improve the consistency, efficiency, and utility of measuring serious injury.

An alternative to KABCO is to develop an improved, cost efficient, and operationally feasible injury performance metric for use by state and local agencies. Research would be necessary to determine the extent to which:

- Other existing databases, such as the National EMS Information System (NEMSIS), trauma registries, hospital discharge databases, etc. can be used to provide a metric;
- Crash reports can be easily linked to the new metric;
- Crash reporting methods would need to change;
- Accuracy and timeliness of data reporting could be improved; and
- The new metric is operationally feasible.

The recommended processes to advance this measure could be supported by several sources of funding and other resources:

- NHTSA Section 408 funding is designed to improve safety data systems in all states, each of which has a Traffic Records Coordinating Committee (TRCC) that could be tapped for assistance;
- FHWA's Highway Safety Improvement Program (HSIP) funds can be used to improve traffic records systems. For example, the Louisiana Department of Transportation and Development uses HSIP funding to support a fulltime position (Law Enforcement Manager) whose responsibility is to work with all law enforcement entities to improve the quality, quantity, timeliness, etc. of police accident reports;
- The National Cooperative Highway Research Program (NCHRP) could support the research necessary to improve the accuracy and timeliness of crash injury reporting;

- The Association of Traffic Safety Information Professionals (ATSIP) is not supported by a funding mechanism but it could be used to identify and implement methods for improving injury data in all states; and
- Various other funding mechanisms, such as NHTSA's 402 program could support research, training, operationalization, and other practices for collecting consistent, accurate, and timely crash injury information.

3.3 PAVEMENT PRESERVATION

Structural Adequacy on NHS

Background and Definition

A distress condition index and specifically a modified version of the Pavement Condition Index (PCI) is recommended as the structural adequacy measure. The PCI is an indicator of the structural integrity and surface operational condition of the pavement.

In conjunction with smoothness measurements, most state agencies collect pavement distress information at the network level on a regular basis. The collected distresses are often aggregated into an overall condition index or score. The application of the distress information includes:

- Measuring the current system-level performance;
- Priority programming;
- Identifying current and future needs;
- Analyzing the consequences of budget decisions; and
- Determining the schedule of work (preservation, rehabilitation, maintenance, new construction, or reconstruction) at the project level.

At the project level, the surface distresses as well as the smoothness measurements are used to validate the adequacy of pavement design and identify the type and extent of maintenance, preservation and rehabilitation needs. In order to determine detailed pavement condition (i.e., characterize both functional and structural/durability condition) across DOTs for use in management and other purposes, there is a need for a common condition index that adequately characterizes pavement structural adequacy. The common condition index must have the following characteristics as a minimum:

1. Should adequately characterize and represent condition.
2. Must be able to model and forecast the new index.
3. Must correlate well with existing DOT pavement indices so as to enable each DOT to relate its existing indices to it.

A standardized condition survey approach that exists in practice is the PCI approach. This method was developed by the US Corps of Engineers, and further verified and adopted by the U.S. Department of Defense and the American Public Works Association. The use of PCI for airfields, roads and parking lots has received wide acceptance and has been formally adopted as standard procedure by many federal and state aviation agencies, and local agencies nationwide. Some DOTs are also using this approach.

The PCI method has several advantages:

- The method has been standardized. ASTM standards D 6433 and D 5340 outlines the procedure for roadways and airfields, respectively.
- It provides a comprehensive approach for distress measurement and condition evaluation. This method includes a comprehensive list of distresses types and the definitions of their severity and extent levels.
- It uses a well established system for weighting and deduct values. The deduct values were developed based on in-depth knowledge of pavement behavior, input from many experienced pavement engineers, field testing and evaluation of the procedure, and accurate descriptions of distress types and severity levels (Shahin, 2005)
- It has been used by aviation and local agencies for almost three decades.
- It produces results with good repeatability if performed by trained and experienced personnel. This means that PCI inspections can be conducted consistently year-to-year, location-to-location, and inspection team-to-inspection team (Broten and De Sombre, 2001[12]).
- It is amenable to varied practice by transportation agencies.
- It uses established thresholds for pavement performance. The PCI also correlates with maintenance and repair needs.
- It produced statistically consistent PCI values for distress measurements from both automated and manual procedure (Shahin, 2005).

Measurement and Calculation

ASTM D 6433[13] defines PCI as a numerical rating of the pavement condition that ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition. The distress information obtained as part of the PCI

[12] Broten, M. and De Sombre, R, "The Airfield Pavement Condition Index (PCI) Evaluation Procedure: Advantages, Common Misapplications, and Potential Pitfalls," Proceedings of the fifth International Conference of Managing Pavement Assets, 2001.

[13] ASTM D 6433 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys

condition survey provides insight into the causes of distress and whether it is related to load or climate (Shahin, 2005[14]).

The rating scale of the PCI is shown in Figure 3.1. Table 3.1 provides a list of distress types used in the PCI method for both asphalt concrete (AC) and Portland cement concrete (PCC) pavements.

The calculation of PCI is based on the results of a visual condition survey. The method involves the following steps:

1. Dividing Pavement Into Sample Units
2. Determining Sample Units to Be Surveyed
3. Performing the Condition Survey - Measuring the severity and extent of each distress type listed in Table 3.1.

Framework for Establishing PCI Thresholds

A modified PCI approach based on the original standard is proposed here to assist with overcoming potential issues with network level data collection without changing the intent of the original standard. This section describes a framework for developing modified PCI thresholds individually for the different highway facility types characterized by location (urban or rural), functional class (Interstate or non-Interstate), traffic volumes (low, medium, and high), and other criteria.

The main criteria typically used by highway agencies to establish threshold values for condition indices are 1) policy objectives (i.e., communication between PMS users and DOT top management) and 2) engineering considerations (extent of deterioration that threatens the integrity of pavement). These two criteria are applied in setting threshold values that ensure that (1) pavements do not deteriorate to the extent that will require costly rehabilitation or reconstruction and can be a hazard to the user public and (2) DOT top management will have a broad picture of true network condition, can prioritize needed maintenance, preservation and rehabilitation, can determine impact of maintenance and rehabilitation needs on agency budgets, and can determine impact of maintenance, preservation and rehabilitation needs on network pavement health.

In developing a framework for a modified PCI for nationwide implementation, the following key issues were considered:

- The proposed approach can potentially be applied by a wide variety of users (Federal, State, and local highway agencies across the nation).

[14] M.Y. Shahin, Pavement Management for Airports, Roads and Parking Lots, Kluwar Academic Publishers, NY, 2005.

- Pavement condition indices currently in use by DOTs across the nation vary widely.
- Although there are several initiatives to harmonize and standardize condition indices across agencies, these initiatives are yet to produce their intended results.
- The proposed modified PCI key distress inputs are based on the distress types reported in HPMS 2010. Thus, all agencies do report the required distresses at a minimum for HPMS sections within their jurisdictions.
- There are approximately 100,000 HPMS pavement sections with all required distress data for computing modified PCI in the U.S.

Thus, the proposed framework is designed with sufficient flexibility to ensure that it is applicable to the different condition indices already in place by highway agencies across the nation and will be suitable for use even after the current systems in place are harmonized. An important aspect of this approach is to use existing HMPS data and state practices as much as possible to correlate state DOT condition indices to proposed modified PCI and maintain current DOT threshold values for characterizing pavement condition.

Thus, with this approach, DOTs will have that information required for relating existing condition indices to the proposed modified PCI and also existing DOT threshold values will be transformed into modified PCI values and used to determine consensus modified PCI values.

Doing so allows all highway agencies to contribute modified PCI data without fundamentally changing their business practices (i.e., distress/condition data collection practices and analysis methodologies) while defining thresholds that are common across all agencies. A step by step description of the proposed framework is presented below:

1. Compute modified PCI for each sample HPMS section.
2. Establish local agency condition index (PSR, PDI, PQI, etc.) for each HPMS section within the agency's jurisdiction.
3. Establish relationship between individual agency condition index and modified PCI for each individual agency.
4. Establish individual agency threshold values for the modified PCI (relationship established in step 3 and existing agency thresholds) and derive consensus thresholds based on agency practices.

Figure 3.1 PCI Rating Scale

Dark Green	Good	100
Light Green	Satisfactory	85
Yellow	Fair	70
Light Red	Poor	55
Medium Red	Very Poor	40
Dark Red	Serious	25
Dark Grey	Failed	10

Source: ASTM D 6433

Table 3.1 List of Distresses in the PCI Method

AC Pavements	PCC Pavements
Alligator Cracking	Blowup/Buckling
Bleeding	Corner Break
Block Cracking	Divided slab
Corrugation	Durability crack
Depression	Faulting
Edge cracking	Joint Seal Damage
Joint Reflection Cracking	Lane/shoulder
Lane shoulder drop off	Linear cracking
Longitudinal and Transverse Cracking	Patching large
Patching and Utility Cut Patching	Patching small
Polished Aggregate	Polished aggregate
Pot holes	Popouts
Railroad crossing	Pumping
Rutting	Punchout
Shoving	Railroad Crossing
Slippage Cracking	Scaling
Swell	Shrinkage Cracks
Weathering/Raveling	Spalling (Joint)
	Spalling (Corner)

Issues

The PCI method has several issues:

- This method is comprehensive and more suitable for project-level condition evaluation. Note that the data needs and applications of condition data are different at network and project levels.
- There are no procedures for continuously reinforced concrete pavement (CRCP) and other pavement types.
- Two pavements with similar PCI rating can warrant different maintenance and repair strategies.
- It can be difficult to develop realistic preservation programs based on PCI data (Broten and De Sombre, 2001).

Although many DOTs use PCI for project-level assessments, it is not typically used as a network-level measure. There are also several issues in terms of consistency of implementation. Based on the current practices among state agencies in pavement condition evaluation based on the Survey results reported in the literature (Papagiannakis et al, 2009[15]; Reza et al, 2005[16]; Walters and Zimmerman, 2010[17]), the following are several areas where standardization is currently an issue:

- **Distress Types.** Figures 3.2 through 3.4 present the percent of State agencies collecting specific distress types by pavement type based on the survey results presented by Walters and Zimmerman (2010)[18]. The figures indicate that most states collect only specific types whereas a fewer states include an extended set of distress types. Although the practices among State agencies can vary with their own needs, there is a commonality in the prominent distress types that they collect. The prominent distress types include load-related and non-load related cracking, rutting, faulting, punchouts, patching, raveling and joint spalling.
- **Overall Index and Rating Scale.** State agencies use a weighted composite index to aggregate various distresses in defining the pavement condition. While some agencies do not calculate an index at all, other agencies use

[15] Pagagiannakis, A., N. Gharaibeh, J. Weissmann and A. Wimsatt, *Pavement Score Synthesis*, Report No. FHWA/TX-09/0-6386-1, Submitted to the Texas Department of Transportation, Austin, TX, 2009.

[16] Reza, F., K. Boriboonsomsin and S.M. Bazalmit, *Pavement Performance Index*, Report No. ST/SS/05-001, Submitted to the Ohio Department of Transportation, Columbus, OH, 2005.

[17] Wolters, A.S. and K.A. Zimmerman, *Research of Current Practices in Pavement Performance Modeling*, Report No. FHWA-PA-2010-007-080307, Submitted to the Pennsylvania Department of Transportation, Harrisburg, PA, 2010.

[18] Wolters, A.S. and K.A. Zimmerman, *Research of Current Practices in Pavement Performance Modeling*, Report No. FHWA-PA-2010-007-080307, Submitted to the Pennsylvania Department of Transportation, Harrisburg, PA, 2010.

different names for their indices. Table 3.2 summarizes various condition indices adopted by the states. States also use different approaches in aggregating various distresses (e.g. separate/combined indices for cracking and rutting), in computing weighted distress indices, and in treating distress and rideability/roughness indices together for determining the overall condition of the pavement.

The rating scales used in evaluating the pavement condition also vary across states. While most states use a rating scale of 0-100 or 0-5 scale, it is not uncommon for states to use different scales. For instance, Illinois uses a 0-9 scale for condition rating survey (CRS) rating, Florida uses a 0-10 scale and Missouri uses a 0-20 scale for distress index.

- **Severity and Extent levels of Distresses.** The practices in defining the severity and extent levels of distresses also vary across states. Table 3.3 illustrates the variation in the definition of distress severity levels across states with an example of rutting criteria used in six states.
- **Length of evaluation section.** The length of the evaluation section also varies with states. Papagiannakis et al (2009) found that the length of the evaluation section varies from 52 feet (Oklahoma) to two to three miles (Ohio), while most states use 0.1-mile or 500-foot sections.
- **Survey frequency.** The frequency of distress survey also varies with states. While 29 states conduct surveys on an annual basis, ten other states have reported to conduct survey on a biennial basis (Papagiannakis et al, 2009).

While most State agencies collect distress information at the network level, there appears to be no or little evidence in the commonality of condition survey practices among the states. The State agencies follow their own protocols that suit their needs likely due to the fact that there are no standardized protocols for the agencies to use.

Furthermore, the variations among agency practices do not allow for a valid comparison of collected information. For instance, Gharaibeh et al[19] (2010) analyzed the pavement condition indices of five State agencies that appeared similar on a 0-100 rating scale. This study concluded that there were significant differences among these indices probably due to the difference in the agency practices and protocols.

[19] Gharaibeh, N.G., Y. Zou and S. Saliminejad, "Assessing the Agreement among Pavement Condition Indexes," ASCE Journal of Transportation Engineering, American Society of Civil Engineering, August 2010.

Figure 3.2 Distress Types Collected for Asphalt Pavements

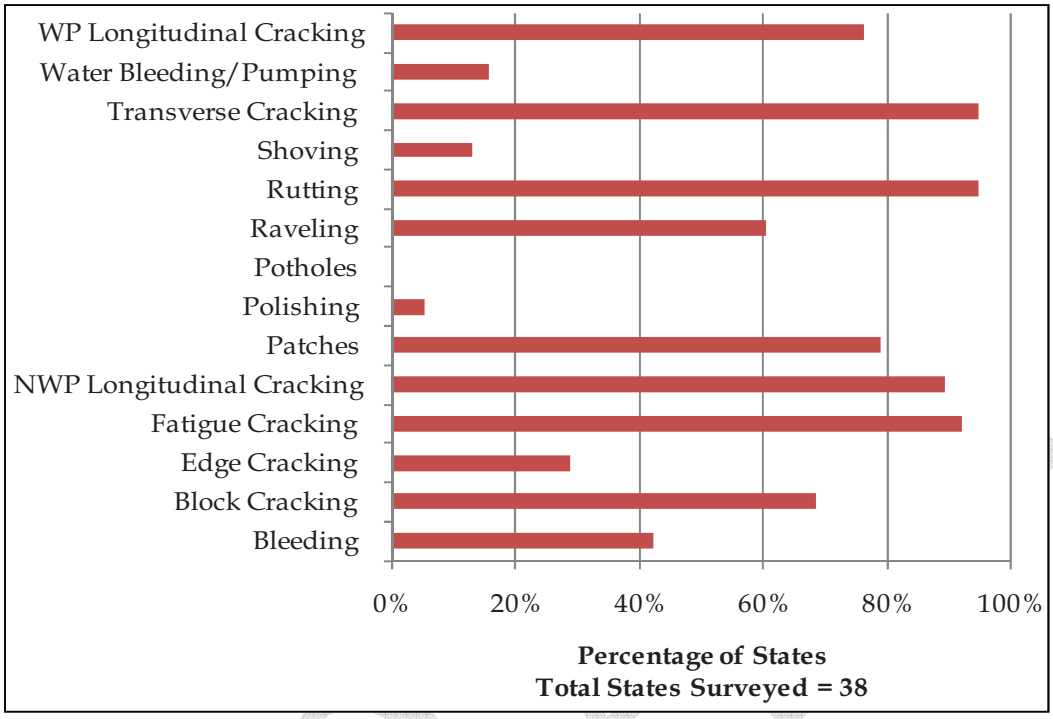


Figure 3.3 Distress Types Collected for Jointed Plain Concrete Pavement

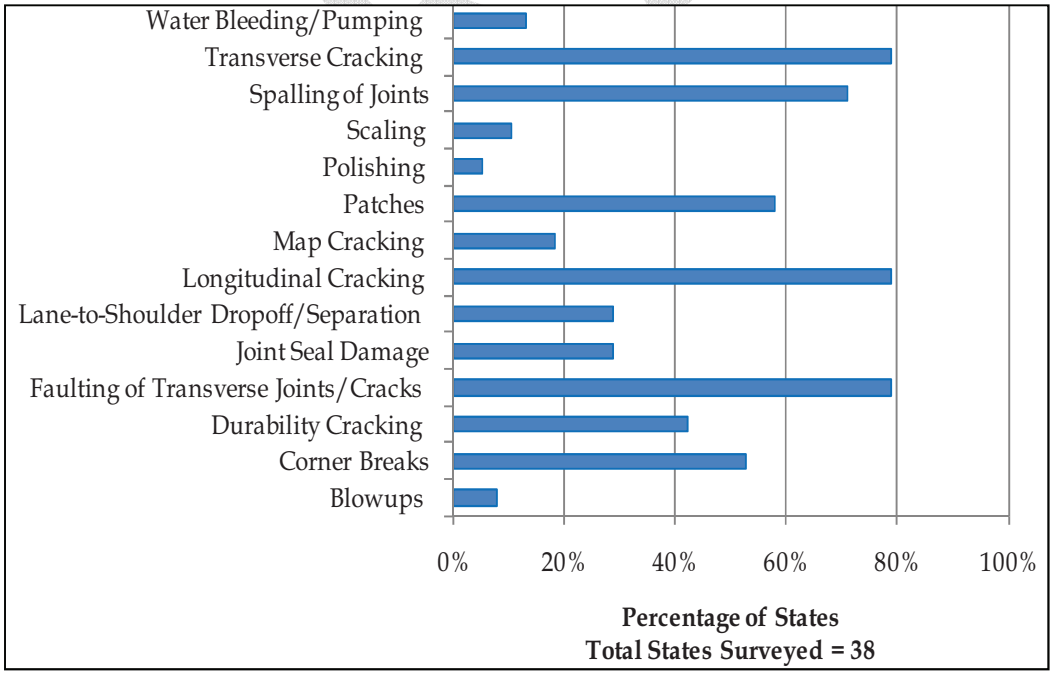


Figure 3.4 Distress Types Collected for Continuously Reinforced Concrete Pavement

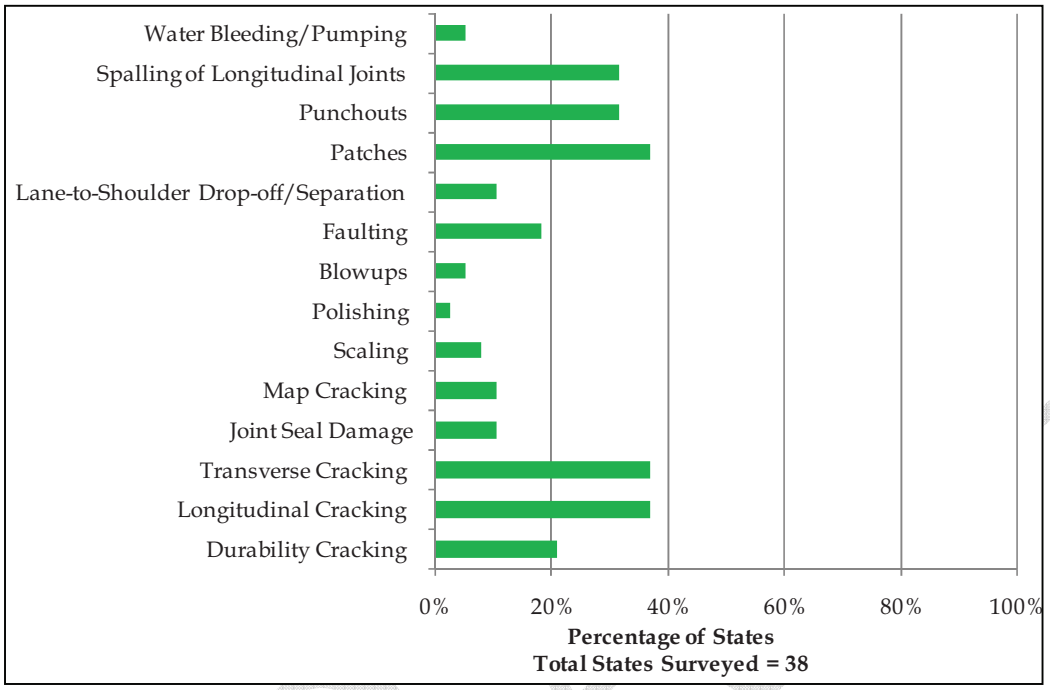


Table 3.2 Pavement Condition Indices Used by State Agencies

Index	States
No index	Maryland, Alaska, Alabama, Arkansas, Connecticut
Pavement Condition Rating (PCR)	California, Georgia, Idaho, Mississippi, North Carolina, Ohio, Maine
Pavement Distress Index (PDI)	Arizona, Wisconsin
Pavement Condition Index (PCI)	Iowa, New York, Vermont, Hawaii
Pavement Structural Condition (PSC)	Washington State
Present Serviceability Rating (PSR)	Wyoming
PMS Category Rating	Nevada
Condition Index	Kentucky
Distress Index (DI)	Michigan
Distress Score (DS)	Texas
Overall Index	Oregon
Overall Condition Index (OCI)	Utah
Overall Pavement Index (OPI)	Colorado, Montana, Pennsylvania
Condition Rating Survey (CRS)	Illinois
Surface Distress Index (SDI)	New Jersey
Surface Condition Index (SCI)	South Dakota
Pavement Quality Index	Minnesota, Tennessee, South Carolina
Critical Condition Index	Virginia
Surface Rating (SR) and Dominant Distress Measure	New York State
Remaining Service Life	Colorado, Michigan, Oregon
Cracking Index, Rutting Index	Florida
Nebraska Serviceability Index (NSI)	Nebraska
Separate cracking index	Idaho
PACES Rating	Georgia

Note: The indices may have changed as the agencies change their PMS practices.

Table 3.3 Rutting Severity Criteria Used in Different States

State	Low or Light	Medium or Moderate	High or Severe	Extreme
Ohio	1/8" - 3/8"	3/8" - 3/4"	> 3/4"	N/A
Oregon	1/4" - 1/2"	1/2" - 3/4"	≥ 3/4"	N/A
North Carolina	1/4" - 1/2"	1/2" - 1"	> 1"	N/A
South Dakota	< 1/8"	1/8 - 1/4"	1/4-1/2"	>1/2"
Florida	Uses a deduct value for each 1/8" increment			
Kentucky	Rates the overall severity by using the average observed severity level.			

Process to Advance Measure

A concerted effort is needed to achieve consistency among agency practices and mobility towards Tier 1. Considering that most agencies use pavement condition data along with smoothness (the Tier 1 measure) to monitor asset performance and make preservation decisions, there is no doubt that some sort of condition based performance measure is appropriate as a Tier 2 measure. The chosen measure herein is PCI, which is a well-documented standard procedure. However, implementation of PCI does face some challenges many of which are related to the general area of condition measurement and would affect any chosen index. The discussion in this section covers the steps that need to be taken to ensure that PCI becomes an industry standard for reporting condition measurement:

- **Harmonization of Distress Measurement**. The practices in measuring and reporting the severity and extent of distresses vary across states. AASHTO and FHWA have taken steps in the recent past to address this situation by developing guidelines and protocols to address this situation for selected distress types. More work needs to be done to expand, validate and formalize these guidelines and protocols for general use particularly for network level data collection. These guidelines should address all types of data collection efforts in practice today—manual, semi-automated, and automated. This effort should be lead by AASHTO or through FHWA's pooled fund efforts. It is recommended that the distress data required to be collected in the HPMS 2010+ Field Manual be the initial focal point of the effort in order to get a modified PCI based on these distresses developed as expeditiously as possible.
- **Modification of the PCI Standard**. As it exists, the PCI is a very comprehensive standard covering several distresses. It is recommended however that a subset of these distresses (i.e., those required to be collected in HPMS 2010+) be combined with IRI in order to develop a modified PCI as has been done by several local agencies who have adopted PCI as a performance standard. The modified PCI could then be converted to a

good/fair/poor scale for national reporting purposes. This approach will require modifications to ASTM D6433 "Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys." These modifications should address (1) size and number of sample units for network level evaluation (2) simplification of reporting of distress severities and densities for network level evaluation such as done in FHWA HPMS 2010+ Field Manual (3) recalibration of deduct value curves in the PCI methodology to account for changes in the definitions of distress severities and densities, and (4) simplification of the PCI rating scale to make it more suitable for network level evaluation. This effort should led by standard setting organizations such as AASHTO and ASTM with inputs from their memberships.

- **Field Verification of the Modified PCI Standard.** Conduct field verification of the proposed method using selected sections from across the US to compare outputs from it to well established local practices for condition assessment. The objective is to ensure that the modified PCI reflects well established and sound local practices. This effort could be led through research and technology implementation activities of the Transportation Research Board and the FHWA.
- **Development of Guidance for Adoption of the Modified PCI Standard.** AASHTO should develop guidance to address short-, medium-, and long-term strategies for the adoption of the modified PCI as an agency standard. For example, in the short-term, agencies can develop transfer functions based on HPMS 2010+ data that relate local condition indices to modified PCI. In the long-term, agencies can modify their business practices (e.g., data collection, storage, analysis, training, equipment etc.) to report the modified PCI directly.
- **Development of a New Tier 3 Pavement Preservation Measure.** The proposed Tier 2 measure described above is a relative indicator of structural adequacy that can be calculated using smoothness and distress data included in HPMS 2010+. It is anticipated that as technology advances, better tools will be available that will allow for a more direct, accurate measurement of structural adequacy for pavements. For example, an improved version of the Tier 2 measure might also consider pavement deflection data. Outlining a new Tier 3 measure that represents the "ideal" pavement preservation measure would help to influence subsequent research and development efforts. AASTHO and the FHWA could lead the effort to develop a new Tier 3 measure.

3.4 CONGESTION/OPERATIONS

Travel Time-Based Metric

Background and Definition

The basis of these measures is the direct measurement of ***travel time*** on the highway network. A wide variety of measures can be created from the same data with virtually no extra effort; once the data collection and processing procedures are developed for the initial metrics, calculation of additional metrics is trivial. For example, the Travel Time Index (TTI) – the ratio of the actual travel time to the ideal travel time – can be easily computed from the same data and that required for travel delay. This section defines several recommended travel time-based metrics. As part of each definition a summary of the calculation methodology is provided—as one or more of these measures transition into Tier 1 measures, a more precise calculation methodology can be developed for practitioners.

Data for Travel Time-Based Metrics

Currently, the most common data for directly measuring congestion come from roadway detectors deployed by transportation agencies on urban freeways. Volume, speed, and lane occupancy data are collected by these detectors, although many older single-loop systems only collect volume and lane occupancy; speed is calculated using assumptions for vehicle and detector zone lengths. Detectors are closely spaced longitudinally, usually less than mile apart, with ½-mile spacing being very common. This technology is often referred to as "point-based" because it measures traffic flow characteristics at a point on the roadway. These data are used in real-time applications such as ramp meter control and traveler information, but nearly all agencies archive the data in some form. ASTM Standard E2665-08, *Archiving ITS-Generated Traffic Monitoring Data*, provides guidance on data processing and archiving methods for these data, including data quality control checks that should be employed.

Figure 3.7 shows the process for computing segment travel times from individual detectors; this can be done at any level of temporal aggregation of the detector data, but the 5- or 15-minute time levels are commonly used and capture congestion patterns better than the hourly level. Note that the same process can be used to aggregate up to an areawide level.

Vehicle probe data from private vendors are increasingly being purchased by transportation agencies. Their great advantage is that measurements are not restricted to locations with roadway devices; this allows coverage onto signalized highways and long distance rural travel as well. In their real-time form, the data are reported as average speeds on relatively short highway

sections.[20] They are collected from the GPS positions of the reporting vehicles over time and distance, allowing travel times for individual vehicles on roadway segments to be calculated.

In addition to private vendor vehicle probe data, which use vehicle-based technology to derive travel times, travel times can also be developed using fixed roadway devices if it is possible to identify individual vehicles as they pass. Detection of toll tag responders has been used for some time as has electronic license plate matching. More recent technologies include BlueTooth readers and vehicle signature identification. Regardless of the technology, the measurements are fundamentally the same and can be treated as such in the calculations.

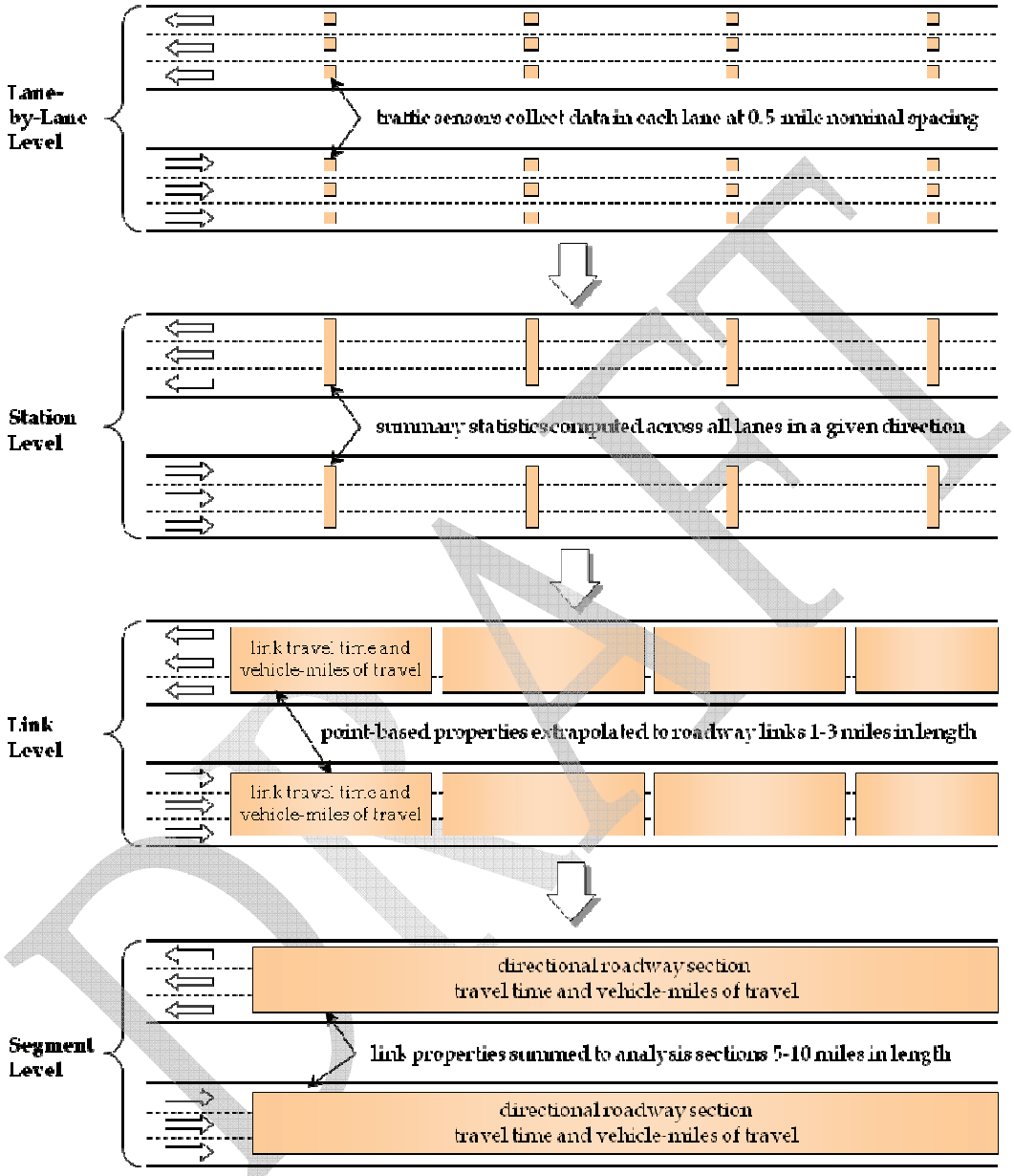
However, all of the probe-based technologies currently only provide a sample of vehicles traversing the network. The travel times are not measured for all vehicles, as is the case with point-based roadway detector data, but are only from vehicles in the vendors' reporting system. Therefore, volumes are not available and VMT cannot be computed. Instead, the "unit travel time", i.e., travel time per vehicle, is computed.

When probe-based measurements are used – until close to 100 percent penetration is achieved -- an estimate of volume is still required to compute total Travel Delay. Transportation agencies maintain extensive traffic counting programs, but the count locations must be matched to the links defined in the vehicle probe data, often challenging due to the different georeferencing methods used. Further, while AADT is widely available and can be used in daily delay calculations, peak period volumes are not. It is therefore necessary that states develop factors for developing peak period volumes from AADT values. This can be done using their existing systems of automatic traffic recorders and urban freeway surveillance systems.

Some states are closer to implementing a measurement-based travel time data collection system than others. In these cases, it would be desirable to accelerate the deployment of the congestion performance measurement system.

[20] The Traffic Message Channel (TMC) representation of the highway network is commonly used; a TMC "link" is usually defined by major intersections/interchanges at the endpoints. TMC length is also provided in the data.

Figure 3.5 Aggregating Traffic Detector Data to Different Geographic Sites



Source: Turner, S., R. Margiotta, T. Lomax. *Monitoring Urban Freeways in 2003: Current Conditions and Trends from Archived Operations Data.* Report No. FHWA-HOP-05-018, Accessed at http://mobility.tamu.edu/mmp/FHWA-HOP-05-018/, December 2004

Travel Delay

Travel delay is expressed in terms of both vehicle-hours and person-hours. Travelers' perceptions of what is unacceptable delay vary based on their typical experience. Therefore, it is recommended that two elements of travel delay be used:

1. Ideal travel based delay, where the threshold is travel under ideal conditions, as related to either the free flow speed or posted speed limit of the facility over which the travel occurs.
2. Acceptable travel based delay, where the threshold is travel for "acceptable" conditions; "acceptable" travel takes longer than the ideal. For national reporting purposes, acceptable conditions should be defined as 80 percent of the free flow speed or posted speed limit, whichever is used to define ideal conditions. Agencies can also define the acceptable threshold in additional ways for their own use. One way is to use a statistical value such as the average or 80th percentile travel time for a facility, trip, or area as the threshold. A problem with this approach is that the threshold will change from year to year.

Travel delay should be based on direct measurements of congestion, starting with actual travel time and demand (volume of vehicles or persons) over a highway segment.

$$Delay = (Actual\ Travel\ Time - Reference\ Travel\ Time) \times Volume \times Vehicle\ Occupancy$$

Calculating the *Reference Travel Time* starts with the travel time that occurs under either the ideal/free flow or the acceptable travel time. The ideal/free flow travel time is estimated based on a highway segment's free flow speed in one of three ways. These are, in order of preference:

1. Empirical speed study following the procedures provided in the latest edition of the *Highway Capacity Manual*;
2. Analytic procedures provided in the *Highway Capacity Manual*; or
3. Posted speed limit.

Ideal/free flow travel time (in hours) is then computed as:

$$Free\ Flow\ (Ideal)\ Travel\ Time = \frac{Highway\ Segment\ Distance}{Free\ Flow\ Speed}$$

The Acceptable Travel Time is then calculated as 80 percent of the Free Flow (Ideal) Travel Time.

Vehicle Occupancy is estimated from local planning data, and volume should come from AADT values matched to locations being measured. Travel delay should be computed for weekday peak periods and for the entire year.

Travel Delay per Commuter

The delay per commuter – which is expressed in person-hours per commuter – is the sum of time lost due to congestion divided by the number of individuals exposed to the congestion *during weekday peak periods*. The intent is to capture that portion of travel most affected by congestion. The "time lost due to congestion" is based on the Ideal Travel Based Delay discussed above.

Assuming that the calculation of the number of persons exposed to congestion is the same as for number of commuters, this measure can be calculated as:

$$\textit{Travel Delay per Commuter} = \textit{Actual Travel Time} - \textit{Free Flow (Ideal) Travel Time}$$

Travel Time Index

FHWA is recommending the use of Travel Time Index (TTI) for its own measurement purposes. The TTI illustrates the comparison of peak period travel time to free-flow travel time, expressed as the ratio of these terms. The TTI includes both recurring and incident conditions and is, therefore, an estimate of the conditions faced by urban travelers. For example, a TTI of 1.40 indicates that a trip that takes 20 minutes in the off-peak period will take 28 minutes in the peak period, or 40 percent longer.

The TTI for a highway segment is calculated as:

$$TTI = \frac{Actual\ Travel\ Time}{Free\ Flow\ Travel\ Time}$$

To derive areawide values for the TTI, a weighted average approach is used using areawide estimates of VHT and VMT, if available. That is, Actual Travel Time for multiple segments is computed as:

$$\textit{Actual Travel Time} = \frac{\sum VHT}{\sum VMT} \times \sum Section\ Lengths$$

Issues

The shift from calculating congestion/operations measures from models to direct measurement will be a significant change for many transportation agencies. However, within two to three years, data for congestion monitoring will be widely available, particularly from private sources. The change will require a significant investment in data collection and/or procurement as well as for data processing. It also will require resolution of several technical issues, including:

- Including VMT as a performance metric. VMT is not in the recommended set, yet is valuable in a number of ways as:
  - As a measure of system throughput;
  - As a "weighting" variable in the calculation of systemwide statistics; and
  - A required variable for calculating Travel Delay as well as Travel Delay per Commuter and Congestion Cost.

- Defining the peak period. Should the peak period be fixed for all facilities or should it be allowed to vary? Should the peak be determined empirically or pre-set using judgment? For cross-agency comparisons, a fixed peak period definition should be used and should include both weekday morning and afternoon periods. The length of time in each period should be either for two or three hours (some decision must be reached on the exact length), with the start and end time of each period being selected locally.
- Extent of highways covered by the measures. Should only designated urban areas be included in the performance reporting or should all NHS highways be covered? It is recommended that both levels of reporting be done, but separately.
- Accuracy and comparability of private vendor travel time data with other data available for agencies (e.g., ITS detector data). Currently, this is unknown and must be studied as a separate effort.

Travel time-related data necessary to do congestion monitoring is commonly used first in real time applications; congestion monitoring is a secondary use of these data. For example, a few states are beginning to use privately-collected travel time data to fuel traveler information systems. The same data can also be used in performance measurement. This multiple use of data will help to justify its expense.

Process to Advance Measure

Although a variety of data sources can be used to create congestion measures as described above, a single data source would be ideal to create a uniform method to be applied nationwide. As of this writing, vehicle probe data brokered by private vendors is the only data source with the required coverage that will be available within the next two to three years; it is not anticipated that transportation agencies will deploy enough roadway-based devices to come close to the required coverage or that another technology will emerge.

However, it is likely that for urban freeways in the top 75 metropolitan areas, agencies will have the ability to monitor congestion performance – at least on the most congested sections – with their own roadway-based equipment. This form of data collection has the advantage of providing matched speed-volume data, which produces more dependable estimates of the congestion metrics (because of more exact volume data). The disadvantage for areawide reporting is that the base is constantly changing due to new deployments (increase in coverage) and equipment malfunctions or construction (decrease in coverage). This situation makes the computation of trends problematic. Given this, if agencies want to use their own roadway-based data, establishing a fixed coverage base is required. This base will have to be used into the future, so agencies need to be comfortable that it adequately represents urban freeways within an area.

As discussed above, vehicle probe data are not without their problems as well. The biggest problem is the matching of travel times from vehicle probes to an

independent source of volumes from transportation agencies. The mechanics of matching locations between the two sources is a major challenge. Even when the geo-matching is completed, the volume data is not of high resolution. Except for a very small proportion of continuous count stations, nearly all of the AADT estimates are based on factored 48-hour traffic counts. Such estimates are subject to sampling error. Breaking AADT estimates down to peak period percentages with a second set of factors compounds the problem. For signalized highways, the situation can be improved by taking advantage of the so-called "system detectors" located mid-block between intersections. These report volumes, but there is a lack of coordination between signal system and statewide traffic monitoring data collection systems that would have to be addressed. Another problem associated with probe data is the resolution of the data. If an archive from the real-time data is available at fine temporal resolution (e.g., five-minute intervals), then there is no problem. However, some vendors also provide archived data at a lower cost than real-time data, and these data can be summarized to higher temporal levels (e.g., all Mondays for a month or year). This difference in results using these two resolution levels is not known, but is extremely important for congestion performance monitoring.

The matching of traffic volume data to vehicle probe data and implications of different resolutions of probe data are areas that require additional research. The FHWA Offices of Operations and Highway Policy Information should jointly lead this research effort, as they have already accumulated much knowledge of vehicle probe data and traffic volumes, respectively.

Given these problems and opportunities, two types of deployment would provide the data necessary to support the Tier 2 congestion metrics:

1. **100 percent based on private vendor vehicle probe data.** States could purchase the data annually either individually or collectively, and do their own processing. Alternately, FHWA could purchase the data for the entire country and develop national congestion metrics for the states. In either case, the volume matching problem has to be addressed. This can be done by requiring the vendors to provide a translation between their georeferencing and the states. At the national level, the Highway Performance Monitoring System (HPMS) data could provide the required volume data (HPMS data are collected and reported by the states).

2. **Vehicle probe-urban freeway hybrid system.** This alternative would use vehicle probe data on all highways except for those urban freeways where the states have deployed their own speed-volume data collection equipment. This has the advantage of providing better estimates on urban freeways because of the matched speed-volume measurements. Many states already have established congestion monitoring based on these systems. The base system would have to be fixed in its coverage. Implementing this system also implies that states will maintain their data collection equipment into the future.

The time frame for implementing the direct measurement approach to congestion monitoring is likely two to three years from now. If a concentrated effort was to be initiated to resolve the technical problems and data collection and purchases, it could be implemented within a year.

Each state should be responsible for deciding the mix of agency-based measurements and private vendor-supplied measurements that will be used. The AASHTO SCOPM should provide oversight on progress made by the states in designing their data collection programs to support congestion/mobility monitoring, and should also provide technical support, which would be in the form of:

1. Providing access to national experts on measuring congestion.
2. Developing a "model" data collection program to support congestion/operations performance measures.

In addition, the results of SHRP 2 Project L02, *Establishing Monitoring Programs for Travel Time Reliability*, should be used as a resource when the report is completed. The proposed implementation of this and other SHRP 2 projects will also provide opportunities for technical support.

Congestion Cost

Background and Definition

There are a number of elements that could be included in the cost of congestion, but extra travel time and extra fuel consumed due to slow speed conditions are two relatively easy factors to estimate. These values are directly related to travel speed and can be derived from other calculations. The calculation process described below uses factors that can be obtained from typical roadway inventory databases or from other performance measure calculations. As with Travel Delay per Commuter, it is based on *weekday peak periods*.

Delay and fuel costs should be estimated separately for passenger vehicles and trucks because the value of time and fuel consumption rates are vastly different. The costs should be developed at the *lowest spatial level possible* (e.g., highway segments) and summed to get aggregated totals.

Delay cost is estimated as a direct function of Travel Delay:

Annual Passenger Vehicle Delay Cost = Daily Vehicle Hours of Delay X *Percent of Passenger Cars* X *Value of Person Time* X *Vehicle Occupancy* X *250 Working Days*

Annual Commercial Cost = Daily Vehicle Hours of Delay X *Percent of Commercial Vehicles* X *Value of Commercial Time* X *250 Working Days*

Where: *Daily Vehicle Hours of Delay* is the *Ideal Travel Based Delay* from above, for weekday peak periods.

Percent of Passenger Cars and Percent of Commercial Vehicles are derived from agencies' traffic monitoring data.

Fuel cost can be calculated by estimating travel speeds, using a simple linear equation to estimate fuel economy for that speed and applying values to the difference between travel time and fuel consumption in congested versus uncongested conditions. The process is evolving, and the new EPA emissions model (MOVES) has an improved fuel economy algorithm that can be used with relatively simple datasets. Alternately, the following equation may be used:

Annual Fuel Cost = *Daily Vehicle Hours of Delay* X *Percent of Passenger Vehicles or Commercial Vehicles* X *Average Peak Period Speed* X *Average Fuel Economy of Passenger Vehicles or Commercial Vehicles* X *Fuel Cost* X *250 Working Days*

Issues

The congestion cost estimation procedures rely on several fixed factors that must determined: value of time, average fuel economy, and fuel cost. If a predictive model for fuel consumption as a function of congestion level is used, this too should be standardized.

Process to Advance Measure

The factors and relationships related to value of time, average fuel economy, and fuel cost identified above should be determined annually with the help of FHWA and should be applied in all states. Other data issues and recommended solutions are the same as those indicated in the Process to Advance Measure section for "Travel Time-Based Metrics" above.

Reliability on the Interstate System

Background and Definition

With regard to highway congestion, reliability is shorthand for "travel time reliability". Several alternative definitions for reliability have been proposed and used. The F-SHRP Reliability Research Program[21] defined reliability this way:

> *… from a practical standpoint, travel-time reliability can be defined in terms of how travel times vary over time (e.g., hour-to-hour, day-to-day).*

[21]Cambridge Systematics, Inc. et al., *Providing a Highway System with Reliable Travel Times*, Report for NCHRP Project 20-58(3) (September 2003) http://trb.org/publications/f-shrp/f-shrp_webdoc_3.pdf.

A slightly different view of reliability is based on the notion of a *probability or the occurrence of failure* often used to characterize industrial processes. From a practical standpoint, reliability metrics can be defined in terms of the distribution of travel times; they describe the size and shape of the underlying travel time distribution. Two metrics based on this concept, which have gained some acceptance with the profession, are therefore recommended:

1. **Buffer Index.** The Buffer Index (BI) is a measure of trip reliability that expresses the amount of extra "buffer" time needed to be on time for 95 percent of the trips (e.g., late for work on one day per month). This buffer is defined as the difference between the 95th percentile travel time and the average travel time over an extended time period (e.g., one year). The BI is the buffer time divided by the mean travel time, to normalize it for comparison purposes. A BI value of 50% indicates that a traveler should allow 50% more travel time than the average if they wish to arrive on-time for 19 out of 20 trips.
2. **Planning Time Index.** The Planning Time Index (PTI) is similar to the BI in that it also uses the 95th percentile travel time as a reference point. However, it is simply the ratio of the 95th percentile travel time to the travel time under ideal of free flow conditions.

In practice it has been observed that the BI can behave in counterintuitive ways for comparing trends. Because it is normalized (divided by) the mean, the base can change as well as the size of the actual buffer. This can lead to a situation where the average travel time shows improvement but the Buffer Index itself shows that more unreliable travel is occurring. This situation can occur if the change in the average travel time is greater than the change in the 95th percentile travel time. However, the BI still provides valuable information: even in the situation described, travelers will indeed face more variability *compared to their typical trips*. Because the PTI has a constant base, this problem does not occur with it.

Both metrics are based on statistics from the underlying travel time distribution for weekday peak periods. The use of pure travel time in the calculation of the metrics is meaningful only for a given trip or facility – for comparison of different conditions, a normalized value must be used to account for distance. This can be done using either the travel rate (inverse of space mean speed) or the TTI[22] as the variable in the underlying distribution, rather than travel time.

The BI and PTI are computed for the spatial level of the data (e.g., link, segment). To aggregate the BI and PTI to larger spatial units, a VMT-weighted average of the lower level spatial units is calculated.

[22] The TTI is the ratio of the actual travel time to the ideal travel time for a facility or trip.

Issues

Many of the issues for the BI and PTI reliability metrics are data and data collection based, as indicated in the Issues section for "Travel Time-Based Metrics" above.

A wide variety of reliability metrics have been developed and tested, so the selection of metrics for national monitoring purposes is not a large issue. The data to support metric development, however, has been the major barrier to implementing reliability. The SHRP 2 L03 project developed simple procedures for forecasting reliability from commonly available data. However, for monitoring purposes, in addition to the prediction error of any model, such procedures will miss subtle changes in the underlying phenomenon. That is, the models rely on using surrogates for reliability rather than measuring it directly.

Another issue is whether output measures should be reported at the national level. Output measures relate to agency activities (e.g., capacity additions and operations activity) as well as changes in the contributing sources of congestion. The latter category includes the characteristics of demand, incidents, work zones, and inclement weather that occur during the monitoring period. Output measures provide both a basis for developing targeted strategies as well as providing explanation as to why a trend occurred. For example, suppose that delay at the national level worsened compared to the previous year. National decision-makers would have no indication as to why this occurred without the benefit of output measures. Tier 3 proposes a limited number of incident- and work zone-related measures, but not enough to provide a deeper understanding of why trends emerged. Individual transportation agencies should have congestion monitoring programs with output measures in place that allow them to pinpoint specific problems and to craft solutions around them. Still, national congestion policy and programs are multi-faceted and having additional data on the sources of congestion problems can be useful.

Process to Advance Measure

The reliability measures can be advanced without dealing with the above issues initially, as long as the issues surrounding the collection of continuous travel time data, as noted under the "Travel Time-Based Metrics", are resolved (the calculation of reliability is based on the same data as for those metrics.) The reporting of additional output measures – in addition to those in Tier 3 -- to help explain trends is an activity that can take place after several years of experience have accumulated with reporting the measures. As mentioned previously, VMT needs to reported along with all of the congestion/mobility measures, but states already have long-standing technical processes for reporting VMT. The linkage of activities to changes in outcome measures would be very helpful to practitioners, but reliability metrics can be advanced without this knowledge; longer term research would be needed to establish these linkages. NCHRP would be the most appropriate venue for this research.

3.5 ENVIRONMENT

Greenhouse Gas Emissions

Background and Definition

Greenhouse gas (GHG) emissions have been identified as a key performance measure to track agency performance in the area of environmental stewardship. This measure will enable transportation agencies to quantify GHG emissions from the transportation sector; assess the effectiveness of various reduction strategies; incorporate GHG emission information into transportation decisions; and support state level climate action plans, executive orders, or other requirements. It will also help DOTs prepare for potential national requirements that may be put in place as part of the next surface transportation authorization and/or future climate and energy legislation.

Issues

Developing a consistent approach across all states to measuring and tracking GHG emissions will be necessary to ensure accuracy and comparability across states, as well as the validity of national-level reporting that relies on aggregate numbers. At the same time, state-level requirements and program goals of individual DOTs may require other measures and data collection. Further, because the demographic profiles, development patterns, economies, energy sources, and mode splits of different states vary considerably, data on absolute emission levels among states will tell only part of the story. Other approaches, including percent reduction relative to state targets, and per capita reduction measures, will provide a fuller picture of states' progress in GHG reductions.

It should also be recognized that, while DOTs play an important role in reducing GHG emissions, other factors beyond the current scope of DOTs' direct responsibility will also be critical to the trajectory of GHG emissions from transportation. Advances in vehicle technologies that improve vehicle fuel efficiency and lower carbon fuels will be critical to GHG reductions. Other exogenous factors that could affect the amount of travel – such as market changes in fuel prices, population change, and changes in economic conditions – need to be taken into account in order to develop meaningful performance measures and targets.

The following issues will need to be addressed to develop a GHG measure for state DOTs:

- Transportation sources to be included in measure – The measure may include all surface transportation modes (rail, transit, road) or only highway-based vehicles; off road vehicles; vehicles using gasoline fuels only or both gasoline and diesel-fueled vehicles. Agencies also did to decide whether to include all on-road GHG emissions, or just those from light-duty sources. While attempting to address both light- and heavy-duty emissions is the more

comprehensive approach, agencies generally have more direct influence over light-duty than heavy-duty emission levels. Light-duty travel is much more closely tied to transportation planning decisions, while truck travel is tied to broader economic factors and also involves trips extending beyond state boundaries. In addition to tracking emissions from surface modes, some states may extend measurement to include water and air transportation.

- Methodology for establishing baseline emissions – Several assumptions need to be discussed and resolved in setting a baseline year (e.g. 1990) and in developing long-range baseline projections. How to manage uncertainty in long-term business as usual (BAU) projections – including uncertainty on the rate of technology advancement, baseline VMT growth, fuel prices, and elasticities in travel demand and mode choice – will need to be determined.
- Unit of measurement to be applied – Measuring GHG emissions requires the use of proxy indicators to estimate the amount of fuel consumed by transportation, then applying emission factors based on the carbon content of that fuel. The primary potential indicators for fuel consumption include changes in VMT, or volume of fuel sales (gasoline only or all carbon-based fuel sales, including diesel). As the carbon content of fuels change over time, the GHG emissions generated by either unit (VMT or gallon of fuel consumed) will change. Whether to consider only carbon dioxide emissions or all GHGs, measured in CO2 equivalents, also needs to be determined.
- Life cycle considerations – GHG emissions measures may include only direct "tailpipe" emissions, or may include "well – to wheel" emissions that include the emissions generated in the production, transport, and disposal of conventional and alternative fuels. Life cycle analyses may also include emissions generated from vehicle maintenance and disposal.
- Accounting for operations, construction, and capital emissions – GHG emissions measures may include or exclude emissions generating by the construction and maintenance of transportation infrastructure, operations of transportation facilities, and emissions generated by capital expenses (e.g., production of transit vehicles),
- Boundary issues – If fuel sales data is used as the indicator of GHG emissions, potential adjustments to state-level fuel sales data may be required to address cross-border fuel purchases for vehicles primarily driven in a neighboring state.
- Double-counting of emissions – Life-cycle emissions for fuel and vehicle production and transportation may be accounted for by the energy or industrial sector.
- Unit of measurement – GHG emissions may be considered on an absolute or per capita basis. Percent reduction, or degree of progress achieved relative to a state-established target, may be appropriate.

- Transparency and reporting mechanisms for GHG measurement – A process and procedures for collecting and reporting GHG emissions data will need to be established, to ensure transparency and consistency in GHG information within a feasible and cost-effective reporting mechanism for all states.

In addition to these issues, a broader question exists: How will GHG emissions ultimately be considered in transportation decisions, and what are the implications for state and national policy? While distinct from performance measurement per se, once these measures are in place transportation agencies will need support and guidance in the use of this data in long range planning and investment, corridor plans, project alternative development and environmental review processes, and operations and maintenance. The application of GHG measures may be directed by state or ultimately national policy that requires consideration of GHG emissions in transportation decisions or sets specific targets for emissions reduction.

Process to Advance Measure

While there are important technical and policy issues involved in accurately measuring GHG emissions from transportation, in many respects the greater challenge in implementing a national GHG reduction measure lies in achieving consensus in the underlying assumptions on how the measure will be defined and implemented.

To address these issues, a process led by AASHTO is recommended, engaging key partners and technical experts. This process would include the following steps.

- **Leadership** – SCOPM and the Special Task Force on Climate Change would jointly lead this effort, and may choose to establish a GHG Emissions Performance Measurement Task Force. The Task Force could draw on members from the Standing Committee on the Environment, the Air Quality Subcommittee, and the Standing Committee on Planning, as well as representatives from other partner agencies and stakeholders. The Task Force would design and finalize the details of a process and working agenda to identify and implement GHG emission performance measures,
- **Participation** – In addition to the leadership of state DOTs, close coordination at the Federal level with the FHWA, FTA, and EPA will be essential. The Task Force may also consider a process for incorporating the input of state resource and energy agencies, and for obtaining broad feedback on the feasibility and sufficiency of various approaches. This may include the use of surveys, working sessions with GHG emissions experts from the research and consulting communities, and discussions with selected states and MPOs that have experience in implementing GHG measures for transportation. As the approach is refined, a workshop with state leaders and partners to present and discuss the findings of the task force may be conducted prior to issuing a final report.

- **Measure definition and implementation** – The Task Force may commission a research study to prepare a final set of options for GHG emissions measures. Given the fluidity of current state and national policies, the research team would work closely with the Task Force throughout the study process. The study report would address the issues identified above and present a discrete number of options to address these considerations. It would also address alternative approaches depending on the nature of Federal GHG emissions requirements that may be established through future transportation authorization or climate and energy legislation. The Task Force would use this information to develop final consensus among states on GHG emission measures, and establish a schedule for Tier 1 implementation.
- **Practitioner Support** – Once implemented, guidance and technical support will be required. This may be provided through AASHTO's Center for Environmental Excellence, as well as by FHWA and the EPA.
- **Research** – A review of the research to date will support the Task Force in establishing a consistent and valid approach to GHG emissions measurement. As states implement these measures, we recommend research to assess additional policies, resources, and tools that may be needed to improve the efficiency and utility of GHG measurement. Research to document states' experience in designing effective strategies to reduce GHG emissions would be useful to identify both successes and barriers in achieving meaningful reductions. Research in collaboration with SHRP C02 may also be useful to support states in implementing GHG measurement in their organizations, and to identify and highlight best practices in this new area.

  Some key research studies have been completed or are underway that will be important resources to the transportation community in examining and resolving these issues. NCHRP Project 20-24(64), *Assessing Mechanisms for Integrating Transportation-Related Greenhouse Gas Reduction Objectives into Transportation Decision Making*[23] reviewed the status of Federal and state policies to address transportation GHG emissions, and examined the range of issues that the transportation sector needs to address in developing a consistent approach to GHG targets and measurement. SHRP 2 C09: *Integrating Greenhouse Gas Considerations into the Collaborative Decision Making Process*, will provide a practitioner guidebook and technical resources for defining, measuring, and projecting GHG emissions under alternative scenarios. The draft framework and guidance for this project is currently being presented at four stakeholder workshops hosted by state DOTs (Colorado, Massachusetts, Minnesota, and Washington), to receive input from state DOTs, MPOs, and their partners before the framework is finalized.

[23] Grant, Michael et. al., NCHRP Web-Only Document 152, Transportation Research Board, January 2010.

In addition, work by a number of individual states and MPOs is rapidly advancing the state of knowledge and practice as regions develop methodologies to assess GHG emissions that will support their specific goals and reporting needs. These include California's work under AB 32 and SB 375, Maryland DOT's Climate Action Plan Implementation, work by Washington DOT to meet HB 2815 requirements, Oregon DOT's initiative to create a toolbox for regions to analysis GHG emissions, and many others.

4.0 Tier 3 Measures

4.1 INTRODUCTION

Tier 3 measures are generally still in the proposal stage and require further study and input from stakeholders in order to advance through the process. Each section below provides a brief definition of the proposed national measure and a description of the steps necessary to move the measure to Tier 2.

4.2 BRIDGE PRESERVATION

Structural Adequacy of NHS Bridges

Background and Definition

This measure is a measure of a bridge's overall structural adequacy. It would be reported on a scale of 0-100, with thresholds defined for good, fair, and poor.

The new measure would be calculated by combining a bridge's various component ratings. For example, National Bridge Inventory (NBI) data could serve as the initial dataset for the measure. The NBI data set includes ratings for a bridge's deck, superstructure, substructure, culvert, inventory load rating, and waterway adequacy. The new structural adequacy measure could be calculated by weighting all or portion of these ratings based on each one's relative importance to overall structural adequacy. By applying weights to the various components of a bridge, it would be possible to consider non-linear deterioration rates. This approach would better reflect the overall structural adequacy of the nation's bridges than the Tier 1 measure, which is based on structural deficiency (SD) status.

As the state of the practice advances, the dataset could be transitioned from more aggregate NBI data to more detailed element-level inspection data. For example, a more advanced version of the measure could be computed using AASHTO CORE Element inspection data and an updated version of the health index calculation currently used by AASHTO's Pontis Bridge Management System. Pontis converts element-level inspection data into a series of ratings for the major components of a bridge - deck, superstructure, substructure and culvert. These indices could replace the NBI condition ratings proposed as a basis for measure. They could be combined into a structural adequacy index using the same weighting approach defined for the NBI-based measure, and bridges could be categorized as good/fair/poor based on the same thresholds.

Process to Advance Measure

All data required to calculate the proposed measure is currently available in the NBI data set. The next step in advancing the measure would be to develop a proof-of-concept that demonstrates its calculation using these data. The two main issues that would need to be addressed during this proof-of-concept effort are:

- Reaching consensus on the relative weight of each of the existing NBI ratings in terms of overall structural adequacy; and
- Reaching consensus on thresholds that could be used to convert the resulting structural adequacy index to a good/fair/poor scale.

These issues could be addressed by analyzing historic NBI data. Research could be done to evaluate the translation of historical NBI condition ratings to a 0-100 score to account for changing rates of deterioration due to bridge age, materials, environmental factors, design type, and other factors. For example, previous research has shown that deterioration rates increase as bridges move from good to fair to poor condition. The weights for combining the various NBI ratings could also be assigned subjectively using an expert elicitation process. Development of this bridge measure using NBI data would provide an opportunity for building consensus on the concept of structural adequacy and good, fair, or poor bridge ratings. The AASHTO Subcommittee on Bridges and Structures, the FHWA Office of Bridge Technology, and FHWA Office of Asset Management could coordinate on advancing this measure.

Moving beyond NBI data as the basis for the bridge structural adequacy measure requires bridge element level data, such as that currently used by Pontis. Current limitations to an element-level measure include the following: not all states collect element-level data, and some that do, only collect the data for state owned bridges. In addition, The AASHTO Subcommittee on Bridges and Structures has recently updated the definitions of the AASHTO Commonly Recognized (CORE) Bridge Elements. It is anticipated that AASHTO will update Pontis to reflect these definitions. However, this transition process is expected to take several years. Given the extent to which the elements are being updated, it is recommended that further work on this measure focus on NBI data until the Pontis updates are complete.

4.3 CONGESTION/OPERATIONS

Incident Management on NHS Routes

Background and Definition

Incident management can be more specifically defined by three basic measures:

- **Incident response time** is the time between the first recordable awareness and the time that the first responder arrives on the incident scene.
- **Roadway clearance time** is the time between first recordable awareness of an incident (detection/notification/verification) by a responsible agency and first confirmation that all lanes are available for traffic flow. This metric has been defined by FHWA's Focus States Initiative: Traffic Incident Management Performance Measures Final Report as a core measure.
- **Incident clearance time** is the time between the first recordable awareness and the time at which the last responder has left the scene. This metric has been defined by FHWA's Focus States Initiative: Traffic Incident Management Performance Measures Final Report as a core measure.

The data to develop these metrics must be collected directly by the agencies actively involved in incident management. The times for "first recordable awareness", "last responder leaving the scene", and "all lanes open for traffic" should be obtained from:

- Dispatcher logs;
- CAD/911 systems; and
- Traffic Management Center operator logs.

The time of "first recordable awareness" is a surrogate for the time the incident actually occurred, which cannot be known with existing technology.

The data for each incident recorded is then averaged for the year and spatial units being reported. The metrics are to be reported for NHS highways, but since the data to support the recommended measures is developed almost exclusively for highway sections where active incident management exists, the number of centerline miles for which the measures apply (i.e., where active incident management programs are in place) also need to be reported.

Process to Advance Measure

The following process is suggested for advancing this measure:

- **Leadership:** FHWA (Office of Operations), in conjunction with the National Traffic Incident Management Coalition, has already embarked on an incident management performance measures effort, as noted above. Therefore, they are in the best position to provide leadership for implementing these measures.
- **Participation:** For incident management, the main deployment issue is how and by whom the data will be collected in a given state or urban area. Incident management programs are structured differently, have different operating agreements, use different technologies. Each program must precisely assign the data collection responsibilities.

- **Practitioner Support:** FHWA should lead the effort to implement incident management performance measures, with the support of other groups, especially the National Traffic Incident Management Coalition, (NTIMC). FHWA should assemble best practices for data collection, management, and reporting to serve as a guide for practitioners.

Work Zone Closure

Background and Definition

The simplest measure for work zone closure can be defined as ***lane-hours lost due to work zone closures.*** This is the number of lanes closed multiplied by the number of hours they are closed. During the course of a given work zone, a new calculation is made every time the number of lanes closed changes. Lane-hours lost are then summed for the entire time the work zone is present. The number of centerline miles where work zones are actively tracked should also be reported.

Lane-hours lost is a good measure of the amount of work zone activity but it is a crude indicator of performance. The effect that a lane closure has on traffic flow depends on both the original volume in relation to the original capacity **and** the number of original lanes. For example, consider a two-lane and a three-lane directional freeway with the same volume-to-capacity (v/c) ratio. If a single lane is blocked on both sections, the capacity loss is greater as a percentage for the two-lane section.

To control for both of these factors, a ***lane-hours lost index*** is recommended. This is the total number of lane-hours lost, computed as above, divided by the number of original lanesopen to traffic prior to the work zone being implemented. In our example, the index would be higher for a work zone on a two-lane directional freeway than for a three-lane directional freeway, both with the same lane-hours lost. To capture the v/c effect, it is recommended that the lane-hours lost index be reported by two broad levels of service (LOS) ranges, as defined by the *Highway Capacity Manual*: (1) levels of service A through C and (2) levels of service of D through F. To determine the appropriate range, the user defines the worst LOS range that describes the operation of the facility **before** the work zone is implemented. The lane-hours lost index is computed for individual work zones. To get a systemwide or other aggregate measure, the index should be computed as the sum of all lane-hours lost divided by the sum of all original lanes present.

Controlling for number of lanes and the v/c relationship in this way is still not perfect. A major problem is all-lane closures, which although rare, do occur. It is desirable to track this severe condition separately. The easiest way to do this is to report lane-hours lost due to all-lane closures.

Finally, another strong indicator of work zone activity is the directional miles of highway affected by work zones. This is the length of the work zone in miles for a single direction of traffic flow.

In summary, the following metrics are recommended to monitor work zone closures:

- Lane-hours lost, total and for all-lane closures only
- Lane-hours lost index, by LOS A-C and LOS D-F, where LOS is determined for the facility without the work zone in place.
- Directional miles affected by work zones.

Process to Advance Measure

The following process is suggested for advancing this measure:

- **Leadership:** As with incident management, FHWA has also embarked on a work zone performance measures effort, and they are in the best position to provide leadership, particularly with regard to data collection practices.
- **Participation:** Current data collection on work zone characteristics is highly scattered. It is likely that most states will have to undertake a new data collection effort in order to develop and report this measure.
- **Practitioner Support:** The National Transportation Operations Coalition, (NTOC), in conjunction with FHWA, should assemble best practices for data collection, management, and reporting to serve as a guide for practitioners.

Metrics for Measuring the Effects of Operations Strategies

Beyond measuring the activities associated with operations, it may be desirable to measure the effects of operations strategies. The congestion measures will capture a major part of the effect, but missing is the impact on *throughput or efficiency*. These measures would be related to the amount of volume (demand) that can be "accommodated" per unit of time. These measures have not seen any use in the profession as ongoing performance measures (some research has suggested them), so additional research is needed to identify data sources, how they would be developed, if they are capable of detecting important changes in conditions, and how operators could use them to make investment decisions. Two such measures are:

1. "Serviceable" VMT per peak period. Here "serviceable" is the acceptable operating speed for a facility. For freeways, 50 mph is a good threshold because it is near the point where flow breaks down. For signalized highways, 80 percent of the free flow speed would be a reasonable breakpoint.
2. Traffic flow momentum (also referred to as Kinetic Energy) per peak period. This is the product of volume and speed for a roadway segment. For example, if a freeway queue is dissipated faster because of effective incident management, more vehicles can be "processed" and at a higher speed.

In addition to efficiency-related measures, other incident-oriented measures should be considered as these both provide insight into national trends in outcomes and will aid local incident management programs. The lane-hours lost and associated index described above for work zones can also be applied to incidents. Secondary crashes due to the existence of a primary incident is another of the FHWA's Focus States Initiative measures that could be a useful measure for national reporting. Likewise, the number of crashes in work zone locations is a very helpful indicator of their effect on users.

The performance of weather management activities is another area of operations that should be given consideration in the future. Travel times and safety are strongly effected during extreme weather events, so having knowledge of what was done for a given set of weather conditions can lead to improvements in practice.

Finally, the recommendations for Tier measures above provide only indicators of the effect on travel times. At some point in the future, it would be desirable to understand the direct effect that incidents and work zones have on travel times and congestion, as well as the contribution of other sources to total congestion (e.g., bottlenecks, inclement weather, special events, and poorly functioning traffic control devices.) Methodologies for determining congestion-by-source are only now emerging, so it will be some time before the profession can agree on the most appropriate method. It should be noted that the data requirements for developing congestion-by-source estimates are intensive: all sources of congestion need to be monitored and fused prior to any analytic procedure being applied.Additional research is required on these metrics and how they would behave under different scenarios and in the case of secondary crashes and congestion-by-source, a common methodology for computing the metric should be developed so that cross-area comparisons can be made. NCHRP is the logical mechanism for conducting such research.

4.4 ENVIRONMENT

Stormwater Runoff

Background and Definition

While there are extensive research and policy discussions currently underway related to stormwater runoff, no precise performance-based definition has been developed. However, current research focuses on efforts to develop a better understanding of the causal effects of stormwater on the quality of water resources; develop more robust approaches to monitoring and modeling stormwater discharges; design effective structural and non-structural measures to improve stormwater quality; and develop new regulatory approaches. Compared to urban stationary structures and industrial sites, highway runoff presents particular challenges in stormwater monitoring and management due to

its linear nature, the wide variety of geographic and hydrological contexts in which roads are built, operated, and maintained, and the episodic nature of rainfall events.

The 2008 report by the National Research Council, *Urban Stormwater Management in the United States,*[24] presented analysis and recommendations that have been central to these discussions. The report called for an integrated stormwater management approach that will support watershed-based water quality strategies, moving from a site-specific monitoring and treatment approach to more comprehensive, multi-source management. The report also documented several key technical and scientific issues that need to be addressed in developing accurate stormwater measurement and stormwater management plans (SWMPs). These issues include a need for improved stormwater modeling, understanding of causal relationships, and the lack of adequate data. As the report states: "At the present time, stormwater modeling has not evolved enough to consistently say whether a particular discharger can be linked to a specific waterbody impairment…in almost all cases, the uncertainty in the modeling and the data (including its general unavailability), the scale of the problems, and the presence of multiple stressors in a watershed make it difficult to assign to any given source a specific contribution to water quality impairment."

The report called for several important changes in the monitoring and management of stormwater, including:

- A shift to stormwater permitting based on watershed boundaries rather than political boundaries;
- System-level integrated stormwater management actions to meet watershed goals, rather than individual controls on specific discharges;
- A shift to continuous "flow-weighted sampling" versus intermittent "grab" samples, which produce highly uncertain results;
- Increased use of nonstructural approaches, or low-impact design methods (LIDs) - including product substitution, better site design, downspout disconnection, conservation of natural areas, and watershed and land-use planning) – rather than reliance on structural or engineering approaches;
- Continuing research to advance watershed modeling capabilities; and
- Further research on hydrologic and water quality processes under different climatic and soil conditions.

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[24] National Research Council of the National Academies, Water Sciences and Technology Board, Committee on Reducing Stormwater Discharge Contributions to Water Pollution, Urban Stormwater Management in the United States, National Academies Press, Washington D.C. 2009

It is in this context that EPA has initiated several national rulemakings under its National Pollutant Discharge Elimination System (NPDES) to establish a program to reduce stormwater discharges from new development and redevelopment and make other regulatory improvements to strengthen its stormwater program, including Effluent Guidelines and Standards for Construction and Development Activities. EPA has issued an Information Collection Request to affected permittee categories. Given the current state of research and regulation, a transportation performance measure for stormwater will need to support DOTs in meeting regulatory requirements under the new rule, and eventually may need to be based on more sophisticated measuring techniques than are currently in widespread use. In addition, a stormwater measure for transportation facilities should support DOTs in implementing and testing the effectiveness of alternative best management practices as they work to design and construct structural and LIDM strategies that improve regional water quality.

Research is underway within the transportation community to help inform transportation agencies in this work. In particular, NCHRP 25-25(56) *Cost and Benefit of Transportation Specific MS4 and Construction Permitting*[25] *and* NCHRP Project 20-68A, SCAN 08-03: *Domestic Scan Program--Best Practices in Addressing NPDES stem and Other Water Quality Issues in Highway System Management* [26] will be important resources. The recent scan of transportation agencies, conducted in July 2009, identified DOT practices that can reduce project delays and improve permit compliance with NPDES.

Because of the ongoing evolution in stormwater management practices and changes in the regulatory framework, the transportation community is challenged to define a stormwater measure that can be consistently applied across all states. Particular issues include:

- Need to identify feasible existing water quality monitoring techniques while anticipating more sophisticated monitoring approaches;
- Consistency with current NPDES (Phase II) requirements as well as future NPDES rule making;
- Limitations in the scientific understanding of causal relationships between facility-specific outflow data and overall watershed quality;
- Variation among DOTS in the permitting authority and process. DOTs are permitted differently; Some fall under a statewide permit, some are included in various municipal permits within urbanized areas, and some are subject to both;

[25] Austin, Lisa, P.E. Geosyntec Consultants, NCHRP 25-25 (56) August, 2010.

[26] Transportation Research Board Annual Meeting 2010 Paper #10-1847

- Different institutional and organizational structures and approaches to stormwater management, tracking and budgeting among DOTs;
- Varying definitions of best management practices versus routine maintenance;
- Varying data collection procedures across states;
- Lack of consistent definitions of water quality measures, particularly given the varying effectiveness of individual measures depending on regional geological and hydrological conditions; and
- Lack of consistent data and accounting procedures on costs of SWM activities;

Process to Advance Measure

To address these issues and develop a stormwater performance measure that can be implemented, AASHTO should lead a continuing process of research and consensus building that engages key partners and technical experts. This process would include the following steps:

- **Leadership** – SCOPM and the Standing Committee on Environment would jointly lead this effort, and form a Stormwater Performance Measurement Task Force. The Task Force could include members from the Standing Committee on Planning and Standing Committee on Design, as well as representatives from other partner agencies and stakeholders. The Task Force would design and finalize the details of a process and working agenda to identify and implement stormwater emission performance measures.
- **Participation** – Close coordination at the Federal level with the FHWA, EPA, and Federal Resource Agencies will be essential. It will also be important to include a representative group of state resource agencies, as well as researchers and NGOs with expertise in water quality, watershed management, and stormwater management practices. An expert panel or workshop approach may be considered to review and vet the draft measurement approach.
- **Measure definition and implementation** – Given the state of science and practice in this area, it is recommended that a phased approach to stormwater measurement be considered. This approach would enable DOTs to develop a nationwide baseline approach to measurement based on current DOT data collection capabilities, and transition to more robust approaches as the state of practice evolves. Phasing will also enable DOTs to respond to the new NPDES rule anticipated in the summer of 2012. The Task Force may commission a research study to prepare a final set of options for stormwater measures and convene a practitioner workshop to review and provide input on these options prior to developing a final recommended approach.

- **Practitioner Support** – Once implemented, guidance and technical support will be required. This may be provided through AASHTO's Center for Environmental Excellence, the North Carolina State Center for Transportation and Environment, and by FHWA and the EPA.
- **Research** – An ongoing program of research will be required to advance modeling and data collection techniques, test the effectiveness of individual measures in contributing to watershed health, and assess the utility of the selected measure(s) in supporting DOT decision making, regulatory compliance, and reporting. Research to document states' experience in designing effective strategies to manage stormwater through both structural and LIDMs would be useful to identify both successes and barriers in addressing stormwater effects.

4.5 FREIGHT/ECONOMIC COMPETITIVENESS

Rural Highway Accessibility

Background and Definition

The potential measure(s) for rural highway accessibility should consider the relative ease by which supply of and demand for freight in a state's rural areas can be met by the agency's investments in connectivity to the national freight network. There are a number of dimensions to this problem:

- Integration with freight network definitions for Tier 1 Measures;
- Definition of geographic access regions for which a state agency can target investment in accessibility;
- The relative mix of commodities and travel in those regions;
- Identifying metrics for which a cause and effect of investment can be determined; and
- Aggregation weighting of the region's metrics into state-wide metrics suitable for comparison at a national level.

<u>Integration with Freight Corridors</u>

The Tier 1 Performance Measures identified by SCOPM involve metrics regarding the nation's Freight Corridors. To facilitate consistent comparison of investments against both the Tier 1 Freight Corridor-based measures, the rural highway accessibility measures should utilize the Freight Corridor as a core element.

Given the Freight Corridor concept, rural highway accessibility can be considered to be the relative ability of a state's rural communities to ship and receive freight by highway to the Freight Corridor network. Once on the Freight

Corridor network, the Tier 1 performance measures can be utilized to characterize the remainder of the freight's journey.

Description of Geographic Access Regions

At a national level, rural accessibility should be presented as a state-level performance measure. To calculate that measure, however, state agencies should have the flexibility to disaggregate the rural regions based on factors unique to the state's geography and approach to investment. One can envision that some state agencies would prefer to disaggregate by district or region, others by county, and others by the Freight Corridor to which connectivity is desired.

Relative Impacts of Commodity Mix and Direction

The accessibility of the freight network for a rural region can be impacted by the commodities being transported, and whether these commodities are originating, terminating, or passing through the region. For example, Table 4.1 presents one potential classification matrix.

Table 4.1 Potential Classification Matrix for Rural Geographic Regions

	Volume of Traffic Connecting to the Nearest Freight Corridor		
Commodity Type	**Originating**	**Terminating**	**Passing Through**
Manufacturing			
Agricultural			
Consumer Goods			

Metrics for Which Investment Can Trigger Improvement

For the purposes of defining rural accessibility metrics, it should be assumed that the Freight Corridor network is fixed. Therefore, for any particular rural location, the relative shortest straight-line distance to the Freight Corridor network is also fixed, and therefore a theoretical best-case travel time can be computed.

A state agency's investments in rural freight accessibility, therefore, should only be measured by metrics relative to best-case travel. Three examples of potential freight accessibility metrics for a particular rural region within a state are:

- Percentage of access travel to the Freight Corridor by highway type (e.g., two lane vs. four lane vs. limited access) or classification (e.g., NHS vs. non-NHS);
- Speed-limit based travel time as a percentage of best-case travel time; and
- Distance of shortest (by time) access trip as a percentage of straight-line distance to the Freight Corridor.

One can envision that variations of the above commodity classification matrix would define procedures for determining the representative "trip" or "trips" for defining the region's access.

Weighting across a State's Regions

Given an approach for identifying rural regions within the state with freight accessibility issues, the state agency's overall metrics for national reporting must be aggregated in an appropriate manner. The relative contribution of freight to each region is a likely starting point for aggregation, but the ability of improvements to rural freight access to generate additional demand for a region should also be considered.

Process to Advance Measure

To address these issues and develop a rural accessibility performance measure that can be implemented, AASHTO should lead a continuing process of research and consensus-building that engages key partners and technical experts. This process would include the following steps:

- **Leadership** – SCOPM would lead this effort in coordination with the appropriate committees considering rural and freight issues, and form a Rural Freight Accessibility Measurement Task Force. The Task Force could include members from the appropriate Standing Committees, as well as representatives from other partner agencies and stakeholders. The Task Force would design and finalize the details of a process and working agenda to identify and implement rural freight accessibility performance measures.
- **Participation** – Close coordination with other rural stakeholders will be required, through an organization such as the National Association of Development Organizations (NADO), as well as coordination with the development of livability performance measures. This coordination can be expected to include coordination with environmental and economic development agencies at both the State and Federal level, as well as with industry stakeholders.
- **Measure definition and implementation** – It is recommended that a phased approach to rural freight access measurement be considered. This approach would enable DOTs to develop a nationwide baseline approach to measurement based on current DOT data collection capabilities, and transition to more robust approaches as the state of practice evolves. The Task Force may commission a research study to prepare a final set of options for rural access measures and convene a practitioner workshop to review and provide input on these options prior to developing a final recommended approach.
- **Practitioner Support** – Once implemented, guidance and technical support will be required.
- **Research** – An ongoing program of research will be required to advance data collection and statistical stratification and aggregation techniques, test the effectiveness of individual measures in identifying both measurable and perceived access, identify how investments in rural access are reflected in

corresponding metrics, and assess the utility of the selected measure(s) in supporting DOT decision making, regulatory compliance, and reporting.

4.6 LIVABILITY

Background and Definition

The terms livability, sustainability, and quality of life are used interchangeably in many contexts to communicate a common understanding of the relationship between community wellbeing, individual health, the economy, and the natural environment. Livability is a multi-faceted, context-based and dynamic social concept. It is often used to describe diverse aspects of surroundings and experiences that shape a community, including the interactions between environmental, economic, spatial, and social components that together are challenging to understand and measure.

One of the key issues related to evaluating livability as a component of a national level performance-based program is establishing a shared definition of what livability is. Most transportation agencies include the terms livability, sustainability, or quality of life in their vision or mission statements, but relatively few explicitly define livability or include it as a specific agency goal or performance measure. There are a few existing programs that have developed different multi-disciplinary definitions of livability. This section provides some background on three relevant programs that can inform the development of a process for establishing national livability measures.

Interagency Partnership for Sustainable Communities

The new Interagency Partnership for Sustainable Communities, a partnership between U.S. DOT, HUD, and EPA announced in June 2009, was established to "transform" Federal policy and encourage a new focus on inter-agency coordination, livability, and sustainability. The Partnership's efforts are guided by six Livability Principles:

1. Provide more transportation choices.
2. Promote equitable, affordable housing.
3. Enhance economic competitiveness.
4. Support existing communities.
5. Coordinate policies and leverage investment.
6. Value communities and neighborhoods.

The Interagency Partnership has a number of initiatives underway, including a competitive grant program administered by HUD. The grants encourage grass roots approaches to achieving local and regional sustainability goals and focus on enabling communities to create transportation choice, housing choice, and

destinations close to home. In addition to framing the livability/sustainability program at the Federal level, the HUD Grant Program is helping to establish a common definition of livability principles across agencies.

USDOT TIGER II Discretionary Grant Program

The USDOT has moved beyond the interagency partnership with its TIGER II Dicretionary Grant Program. The Final Notice of Funding Availability, released on June 1, 2010, defines livability investments by stating that TIGER II projects should not only deliver transportation benefits, but should also designed and planned in such a way that they have a positive impact on qualitative measures of community life. This element of long-term outcomes delivers benefits that are inherently difficult to measure. However, it is implicit to livability that its benefits are shared and therefore magnified by the number of potential users in the affected community.

For the TIGER II Grant Program, DOT considered whether the project furthered the six livability principles and gave particular consideration to the first principle, which prioritizes the creation of affordable and convenient transportation choices. Specifically, DOT evaluated whether a project would improve the quality of the living and working environment of a community through a qualitative assessment of whether the project: (1) Will significantly enhance or reduce the average cost of user mobility through the creation of more convenient transportation options for travelers; (2) will improve existing transportation choices by enhancing points of modal connectivity, increasing the number of modes accommodated on existing assets, or reducing congestion on existing modal assets; (3) will improve accessibility and transport services for economically disadvantaged populations, non-drivers, senior citizens, and persons with disabilities, or will make goods, commodities, and services more readily available to these groups; and/or (4) is the result of a planning process which coordinated transportation and land-use planning decisions and encouraged community participation in the process.

CalTrans Smart Mobility 2010 Framework and California Regional Progress Report

The CalTrans Smart Mobility 2010 Framework is one of the most recent and impressive examples of a performance-based approach to transportation planning and investment that is dedicated to the principles of livability, sustainability, Smart Growth, and context sensitive solutions. According to the framework, "Smart Mobility moves people and freight while enhancing California's economic, environmental, and human resources by emphasizing: convenient and safe multimodal travel, speed suitability, accessibility, management of the circulation network, and efficient use of land."

The framework establishes six Smart Mobility goals, similar to the six Livability Principles adopted by the Interagency Partnership, which are supported by 17 Smart Mobility Performance Measures (SMPMs). The goal of each of these

measures is to demonstrate the relationship between specific land use and transportation decisions and consequent effects on economic, social, and environmental conditions. For each performance measure, different metrics are recommended that best demonstrate this relationship based on the land use or community context being addressed. Table 4.2 shows the relationship between the framework's goals, performance measures, and recommended metrics.

The California Progress Report, compiled by Caltrans and released in 2007, serves as a snapshot of regional conditions and progress across the state. The information is gathered from the Regional Blueprints and intended as a resource for decision-makers and stakeholders as they work to improve the economic, social, and environmental well-being of the state. The intent is that the Progress Report will support decisions that lead to:

- A more efficient and effective transportation system and land use pattern;
- A strong and sustainable economy; and
- Progress along the dimensions of place, prosperity, and people (i.e., the "3Ps") which define quality of life for all Californians. The 3Ps fully incorporate and expand on the environmental, economic, and social equity dimensions (i.e., the "3Es") that have been widely used by the regions of California, Caltrans, and many others as a conceptual foundation for policy and planning.[27]

The Regional Blueprint program is still relatively young, so the Progress Report is not intended to measure the effectiveness of the programs, but instead to provide a context within which the implications of the Blueprint planning-related decisions can be found. Figure 4.1 illustrates the relationship between the Regional Blueprint goals, the policy choices that are made as a result, and the outcomes tracked in the Progress Report.

[27] (http://calblueprint.dot.ca.gov/index_files/CA_Regional_Progress_Report_2007.pdf), p. 02

Table 4.2 Smart Mobility 2010 Goals and Performance Measures

Goal	Measure	Example Recommended Metric
Location efficiency	• Support for Sustainable Growth	• Consistency with regional Sustainable Communities Strategy
	• Transit Mode Share	• Percentage of trips within a corridor or region occurring by bus, rail, or other HOV form
	• Accessibility and Connectivity	• Number of households within 30 minute transit ride of major employment center
Reliable mobility	• Multimodal Travel Mobility	• Travel times and costs by mode between representative origins and destinations, aggregated over corridor or region.
	• Multimodal Travel Reliability	• Day-to-day variability of travel times between representative origins and destinations by mode
	• Multimodal Service Quality	• Mode-specific and blended LOS measures
Health and safety	• Multimodal Safety	• Collision rate/severity by travel mode/facility
	• Design and Speed suitability	• Conformance with guidance identifying suitable design elements and traffic speed with respect to mix of modes, adjoining land uses, and area character
	• Pedestrian and Bicycle Mode Share	• Percentage of trips within a corridor or region occurring by walking or cycling
Environmental stewardship	• Climate and Energy Conservation	• VMT per capita by speed range relative to State and regional targets
	• Emissions reduction	• Quantities of criteria pollutants and GHGs
Social equity	• Equitable Distribution of Impacts	• Impact of investments on low-income, minority, disabled, youth, and elderly populations relative to impacts on population as a whole
	• Equitable Distribution of Access and Mobility	• Comparative travel times and costs by income groups and by minority and non-minority groups for work/school and other trips
Robust Economy	• Congestion Effects on Productivity	• Time lost to congestion by trips that are economically productive and/or sustaining of essential mobility, measured as vehicle hours of delay
	• Efficient Use of system Resources	• Additional VMT that are associated with economic productivity and/or sustaining of essential mobility compared with system expansion cost and impact
	• Network Performance Optimization	• VHD per capita, per lane mile, per private vehicle mile, per transit revenue mile, and in total
	• Return on Investment	• Person miles and revenue per lane mile of road, per transit revenue mile and per dollar invested).

Source: Smart Mobility 2010 Framework

Figure 4.1 California Progress Report Goals, Policies, and Outcomes

Source: 2007 California Progress Report, http://calblueprint.dot.ca.gov/index_files/CA_Regional_Progress_Report_2007.pdf

Process to Identify and Advance Potential Measures

The descriptions of the three programs above provide some guidance toward elements of a proposed national level livability program. This guidance can help shape both selected measures, as well as the process to arrive at those measures:

- Livability is multidimensional – No matter how it is defined, livability has many dimensions, which no single measure can capture. More than one measure will need to be identified to effectively capture the livability of a state.
- Livability is contextual – What makes a place livable is not the same across every type of area. For example, transit level of service or walkability will be quite different in an urban area than in a rural area, or a suburban area. Therefore, different measures, or different thresholds are needed in different contexts.

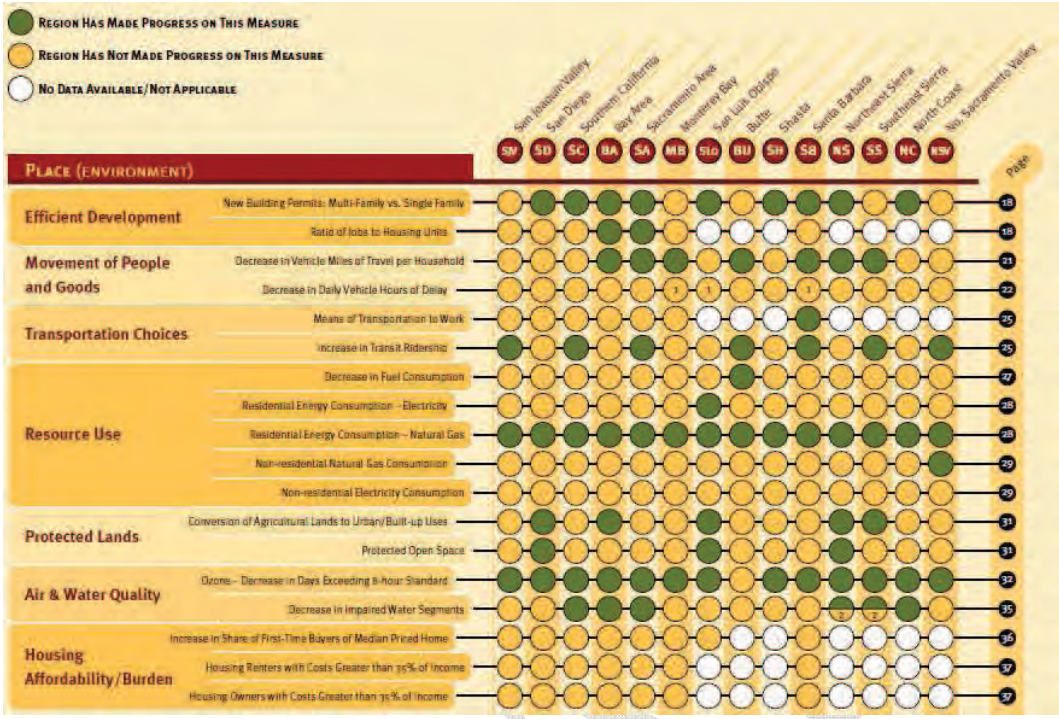
- Livability is multi-disciplinary – The elements of livability include land-use, the environment, economics, and other social dimensions. Therefore, the process to identify a set of measures that are effective should involve experts representing a range of agencies and perspectives.

The California Progress Report (described above) provides an excellent model for a collaborative process leading to a set of performance measures that will be reported on consistently by multiple agencies within a region. To select the indicators, an Advisory Team comprised of representatives from MPOs, COGs, Caltrans and other relevant agencies was formed. Members of the Advisory Team identified the indicators that were important to their region in measuring progress toward the stated objectives. These indicators, along with others employed around the country, were combined to create a common set for consideration. A set of criteria was then used to evaluate the potential of each indicator:

- Alignment (with existing visions, goals, or measures);
- Quantifiability;
- Outcome-based;
- Clarity; and
- Availability of data to measure the indicator.

The result of this process is a set of 27 indicators that can be used at the regional level. They span three categories of outcomes: place (environment), prosperity (economy), and people (equity). Figure 4.2 shows the 18 indicators relating to Place (see link to full report for complete set of indicators), and whether each region has made progress (measured in percent changed) in relation to itself. The purpose is not to compare one region to another, but to provide an overall snapshot of how the state is doing on many dimensions, and to help regions in determining their own progress.

Figure 4.2 California Progress Report "Place" Indicators



Source: California Progress Report, p. 13,
http://calblueprint.dot.ca.gov/index_files/CA_Regional_Progress_Report_2007.pdf

A similar process could be applied to the effort to identify national-level performance measures for livability, using SCOPM as the base group to provide the input and collaboration and to guide the process. The following outlines a proposed process, based around five steps or activities:

- **Leadership** – SCOPM will serve as the coordinating body and form a Livability Task Force. The Task Force could include members from the Standing Committee on Planning, the Standing Committee on the Environment, and representatives from other partner agencies and stakeholders. The Task Force will design and finalize the details of a process and work agenda to identify and implement livability performance measures, with consideration of the suggested steps outlined here.
- **Participation** – As a multi-disciplinary topic, the input and perspective of a range of agencies is critical to the success of the identification of national livability performance measures. In addition to members of the Task Force, other stakeholders should be included in a performance measures identification and selection process. For example, input from HUD, EPA, and selected MPOs would provide insights from agencies that have been engaged in the conversation about livability and how to measure it.
- **Measure definition and implementation** – The Task Force will lay out a process for selecting a measure (or set of measures), and an implementation

process and schedule to be used to track livability. The Task Force, with input from stakeholders will then use this process to come up with a final program. Based on the findings from the review of existing programs, Figure 4.3 provides one option.

- **Practitioner support** – Livability measures are not as commonly used as measures in other categories, and therefore agencies asked to track them may need additional background and technical support. The Task Force will lead an effort to create a guidebook for agencies that outlines details for each of the measures, including considerations for implementation, data sources, calculations, and other relevant issues. This document will also provide specifics on measure reporting (e.g., frequency and format) and any other requirements.
- **Research** – Although strategies to measure livability are primarily in their infancy, there is a great deal of research going on that will advance the state of the practice. For example, the Interagency Partnership recently awarded almost $100 million through the Sustainable Communities Regional Planning Grant program. The recipients of these grants will be tackling a range of issues related to livability at the community level, and will be an excellent resource for best practices and successes and challenges of the implementation of livability performance measures. In addition, related efforts are underway through NCHRP, SHRP, by FHWA, and other entities. Events such as TRB's Transportation for Livability Communities Conference in October 2010 will also provide relevant research and insights, given its emphasis on charting a research agenda.

To leverage these efforts, the Task Force will review research and findings on the validity of livability performance measures, identify gaps in the research, and propose additional research ideas to assist in moving livability first to the Tier 2 measure category, and ultimately to the Tier 1 measure category area.

Figure 4.3 Sample Livability Measure Framework

To create a set of measures that are multi-dimensional, flexible, and multi-disciplinary, the Task Force could identify a set of livability "elements", and then offer flexibility of measures within that in a "menu" form. Each state agency would have to choose one measure from each element to track consistently each year. This offers some standardization but also allows flexibility for agencies that are dealing with different issues or have different livability priorities. These measures would be calculated on a percent change basis to show direction of progress for each state, while offering an overall snapshot across the elements.

Table X. Proposed Livability Measures Framework

Livability Elements	Sample Measures
Place (Environment)	Commute mode share
	Transit ridership
	Percentage of funding spent to support existing communities
Prosperity (Economy)	Number of jobs per capita
	Per capita income
People (Equity)	Number of households within 30 minute transit ride/drive of major services (schools, shopping, employment, hospitals, civic spaces)
	Percentage of income spent by low-income households on housing and transportation costs (CNT's housing and transportation index)

draft final report

NCHRP 20-24(37)G - Technical Guidance for Deploying National Level Performance Measurements

Volume 2 - Implementation

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1.0 Introduction

Responding to recent trends that have placed greater emphasis on public-sector accountability for more effective performance, the American Association of State Highway and Transportation Officials (AASHTO) adopted a federal surface transportation authorization proposal that included a national performance measurement program focused on critical national goals. The proposal is based on the notion that a national performance measurement/management program would:

- Focus needed attention on key national goals;
- Provide more transparency and accountability for the federal program;
- Build on the considerable performance measurement/management work already occurring in individual state DOTs;
- Help make the case for a larger federal program; and
- Drive better performance results through an iterative process of establishing best practices across states and determining which strategies are most effective in each particular goal area.

Consistent with this proposal, AASHTO established seven task forces which have worked for nearly two years to identify performance measures that states could use to track the impact of investments in the national goal areas. This effort has resulted in the designation of three tiers of performance measures for consideration in a national performance-based structure by which states would report annually their performance in these goal areas, using nationally-consistent measures relative to state-developed targets for those measures. The measures in the Table 1.1 Tier matrix were aligned against three criteria:

- Is there general consensus on the definition of the measure?
- Is there a common or centralized approach to data collection in place?
- Has the availability of consistent data across states been established through national comparative analysis or other research effort?

Tier 1 measures meet all three criteria and are considered complete or nearly complete and ready for deployment, with the understanding that there could be further improvements to the measures in the future. Tier 2 measures meet one or two criteria and require further work before they are ready for deployment. Tier 3 measures are generally still in the proposal stage and require further study and input from stakeholders in order to advance through the process of adoption. As some measures are currently more developed nationally, the level of detail for each measure varies. For some formulas are well established, but data issues

must be overcome; for others data sources may be consistent, but field measurement varies.

Table 1.1 Recommended Tiered Measures

Goal Area	Tier 1 – Ready for Deployment	Tier 2 – Additional Development Required	Tier 3 – Proposal Stage
Safety	• 5 year moving average of the state number of fatalities	• 5 year moving average of the state number of serious injuries	
Pavement Preservation	• IRI on NHS	• Structural adequacy on NHS	
Bridge Preservation	• Deck area of structurally deficient bridges on NHS		• Structural adequacy of NHS bridges
Congestion/ Operations		• Travel time-based metric • Congestion cost • Reliability on the Interstate system	• Incident Management on NHS Routes – Response time – Clearance time • Work zone closure
Environment		• GHG emissions	• Stormwater runoff
Freight/Economic Competitiveness	• Speed/travel time on freight corridors • Reliability on freight corridors		• Rural highway accessibility
Livability			*Definition to be identified and draft measures proposed*
Connectivity			*TBD in Future Work*

Source: AASHTO Standing Committee on Performance Management

Volume 1 defines each measure, provides a calculation methodology for each measure, lists specific data needed for each calculation, specifies methods for establishing targets, and identifies deployment issues.

This document provides guidance for AASHTO to develop and adopt performance measures for goal areas. It is organized as follows:

- Section 2 presents **short-term implementation guidance for the Tier 1 measures**. Key steps include formal adoption of Tier 1 measures by AASHTO and development of protocols for compiling and reporting the adopted measures. More detailed steps for ensuring consistency in implementation between states on specific measures are included in Volume 1.

- Section 3 summarizes steps required to continue **development of the Tier 2 and Tier 3 measures**. The technical details of these future measures are discussed in Volume 1.
- Section 4 provides guidance on the overall **implementation of a nationwide performance program**. A key activity in this area is to develop a structure and process within AASHTO to ensure that individual measures progress and to maintain the overall measure matrix as the nationwide program evolves.
- Section 5 addresses the development of a **technical support program to assist states in adopting performance management**.

2.0 Short-Term Implementation of Tier 1 Measures

2.1 OVERVIEW OF TIER 1 MEASURES

This sections provides a summary of the Tier 1 measures. For more details refer to Volume 1.

Five Year Moving Average of the State Number of Fatalities

The proposed measure is defined as the average annual number of fatalities over a five-year period for each state. A fatality is defined as a death of a person (motorist or non-motorist) occurring within 30 days of a crash involving a motor vehicle traveling on a roadway customarily open to the public, which is consistent with the definition used for the National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS).

International Roughness Index (IRI) on NHS

The proposed measure is defined as the percent of lane-miles on the NHS classified as "good", "fair", and "poor", as determined by thresholds for the International Roughness Index (IRI). AASHTO PP 37 defines the IRI as "a statistic used to estimate the amount of roughness in a measured longitudinal profile." This measure is first calculated by determining the value of IRI for all roads on the NHS. Using thresholds as defined by the Federal Highway Administration (FHWA), identify the lane-miles classified as "good" (IRI < 95), "fair" (IRI between 95 and 170), and "poor" (IRI > 170), and divide by total lane-miles to get the percent of pavement within each category.

Deck Area of Structurally Deficient Bridges on the NHS

The proposed measure is defined as the sum of the deck area of a state's NHS bridges flagged as Structurally Deficient (SD) in the National Bridge Inventory (NBI) divided by the deck area of all of a state's NHS bridges, expressed as a percent. SD status is determined by the FHWA based on NBI data submitted by state DOTs. A bridge is classified as SD if:

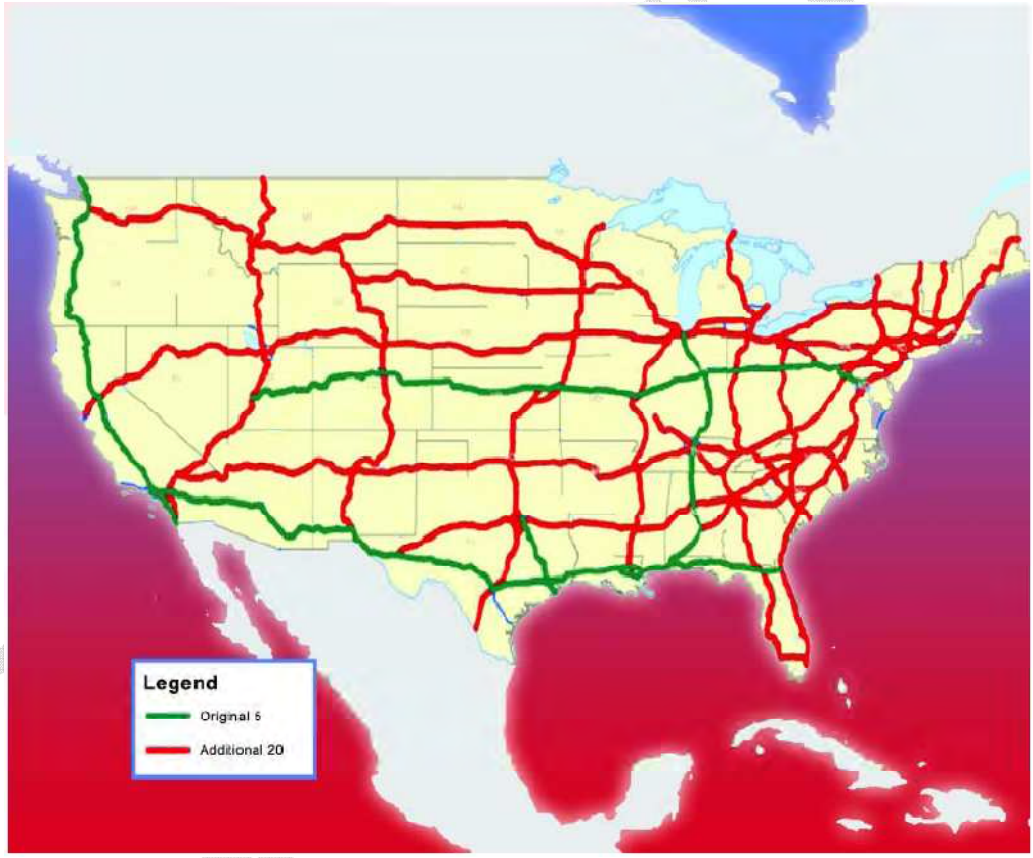
- The condition of its deck, superstructure, substructure, and/or culvert is rated 4 or less (on a ten-point scale), OR

- Its structural condition or waterway adequacy is rated 2 or less.[1]

Speed/Travel Time on Freight Corridors

The proposed measure is defined as the average speed or travel time along a section of one or more freight corridors. Figure 1.1 illustrates the proposed freight corridors, which have been identified by the Federal Highway Administration as having freight volumes sufficient enough to measure performance

Figure 2.1 Proposed Freight Corridor Network



Source: FHWA.

There are several different considerations of the measure:

- At the individual freight corridor level, the proposed performance measure is the average speed (24-hour day) of the entire corridor.

[1] FHWA Non-regulatory supplement for 23 CFR 650.409, http://www.fhwa.dot.gov/legsregs/directives/fapg/0650dsup.htm

- At the state level, the proposed performance measure is the average speed (24-hour day) of each freight corridor crossing the state.
- Travel time is proposed to be measured at the major "truck lane" level.

Reliability on Freight Corridors

The proposed measure is defined as the amount of time, expressed as a percentage, that has to be added to average travel time to be "on time" for 95 percent of trips made in a corridor. Such a classification of measure is often referred to as a "buffer index."

If average travel time is one hour and the buffer index is 50 percent, a traveler would need to allow one and a half hours for the trip to be 95 percent confident of arriving on time. To calculate the buffer index, the length of each corridor is divided by the average speed on that corridor (from the freight speed measure) to obtain the average travel time. Speed data are then used to calculate how much travel time is required to ensure that 95 percent of the trips on the corridor will be on time. Subtracting the average travel time from the 95th percentile travel time and dividing the result by the average travel time expresses the percent of time above the average a traveler needs to allow on that corridor. Like the freight speed measure, this measure is calculated both for entire freight corridors (crossing multiple states) and freight corridors within a state, and can also be calculated for major intrastate or multi-state "truck lanes".

2.2 DEVELOP MEASURE REPORTING PROTOCOL

It is recommended that AASHTO develop formal guidelines for compiling and reporting the adopted Tier 1 measures. These guidelines should include the following:

- **Designation of responsible party.** Reporting of measures can be done individually by each State DOT and submitted to a single entity, e.g., AASHTO, or a single entity can be charged with calculating all measures, and provide DOTs with the opportunity to review them before they are officially reported. This option is possible because the Tier 1 measures can be calculated with national data sets.
- **Mechanism for calculation and compilation.** Options for calculating and compiling the measures from State DOTs include the following: 1) Develop a standard report form, for example in document or spreadsheet format, that can be filled out and submitted or exchanged electronically, or 2) Develop an on-line tool that supports measure calculation and submission. For example, this tool could enable agencies to do the following:
  - Log-on to a secure system.

- Access national data that could be used to calculate the measures, such as the most recent Highway Performance Monitoring System (HPMS) or National Bridge Inventory (NBI) data sets.
- Select an option to automatically calculate the measures based on these data sets.
- Review the results generated automatically and override them with results developed using DOT-specific data if necessary.
- Submit the measures to a central database.
- Review historic performance trends based on measures submitted in previous years.
- Select peer states and perform an ad-hoc comparative analysis.

Option (1) is suggested for immediate deployment, but option (2) is recommended as the preferred approach. Such a tool can be developed in parallel to implementation of national performance measurement and could be completed within one year.

- **Performance report template.** It is recommended that a standard report be developed that can be used to communicate the measure results from the State DOTs. This report could be distributed as a standard .pdf document and/or presented electronically, for example in an interactive format through the tool envisioned above. It is recommended that as time goes on, that the report included historic trend information. A key decision in developing the report template is the preferred level of annotation. It is recommended that any annotation, such as a written description of historic trends and emerging themes, focus on national averages rather than state-specific results. This approach will minimize the level of effort required for annotation. At a minimum, the national performance report should include the following:
  - An overview of each measure (technical description and layman description);
  - National average for each measure, shown over time; and
  - Latest results by State.
- **Calendar for measure submission, review, and reporting.** It is recommended that the reporting process be conducted annually, similar to the schedule used for other national data programs, such as HPMS and NBI programs. The calendar should include a date for submittal, time for compilation and report generation, and a date for issuing the report. This schedule may vary depending on the chosen mechanism above for reporting.
- **Reporting responsibility.** An "owner" of the reporting process should be identified, and given overall responsibility for ensuring that the calculation, submittal, and reporting process proceeds as planned.

2.3 ADOPT TIER 1 MEASURES

A major step in the implementation of the Tier 1 measures is for AASHTO to officially adopt them. It is anticipated that votes on adoptions of Tier 1 measures would occur at each year's AASHTO Annual Meeting, following a process similar to that used at the 2010 AASHTO Annual Meeting.

A resolution is recommended that defines the overall national level performance measurement framework and concepts, but with separate votes on each measure. Voting individually on performance measures will allow a subset of the Tier 1 measures to be adopted initially, as opposed to "all or nothing". This also provides the framework for approving new measures in the future as Tier 2 measures become ready for deployment and move into Tier 1.

If some of the measures are not approved, then they should follow the approach outlined in the following section for Tier 2 and Tier 3 (i.e., the responsible task force for each measure should be assigned to further refine or develop each measure and address concerns that prevented adoption of the measure).

Ongoing vetting with other relevant AASHTO committees, such as the Standing Committee on Planning (SCOP), and states is recommended in advance of the meeting.

2.4 RECOMMENDED TIMING

The main item on the critical path of short-term implementation schedule is adoption of the Tier 1 measures by AASHTO. It is anticipated that votes on adoptions of Tier 1 measures would occur at each year's AASHTO Annual Meeting, following a process similar to that used at the 2010 AASHTO Annual Meeting. In the future, as other measures are moved to Tier 1 (see sections below), they will follow the same implementation process.

The other actions described are not needed without this approval. However, it is recommended that the reporting logistics options described above be vetted and narrowed prior to the next AASHTO vote in 2011. These decisions will provide AASHTO members with additional context on the implementation of the Tier 1 measures before they vote to adopt them.

3.0 Development of Tier 2 and 3 Measures

The Tier 2 and Tier 3 measures provided in Table 1.1 require further development and consensus before they are ready for deployment. This section summarizes key steps required to develop and finalize these measures so that they can be transitioned to Tier 1 and become ready for deployment nationwide. For more technical details regarding these measures, refer to Volume 1. Measure-specific development guidance is also contained within each measure subsection in that Volume.

Table 3.1 defines the key players who are recommended to lead the development effort for each measure, including those that should be consulted during the process.

3.1 TIER 2 MEASURES

Five-Year Moving Average of the State Number of Serious Injuries

- Assess the current state of practice with regard to the methods states use to define, document, and measure incapacitating injuries.
- Prepare precise recommendations on how the measure should be defined and specific action steps for implementing any necessary changes.
- Devise a communications plan to disseminate the information and work with appropriate officials in all states to adopt the definition and implement the action steps.

Structural Adequacy on NHS

- Harmonize distress measurement and reporting across states, building upon AASHTO and FHWA guidelines and protocols for selected distress types.
- Modify the PCI standard by combining a subset of PCI distresses (i.e., those required to be collected in HPMS 2010+) with IRI in order to develop a modified PCI as has been done by several local agencies who have adopted PCI as a performance standard.
- Conduct field verification of the modified PCI standard using selected sections from across the US to compare outputs from it to well established local practices for condition assessment.

- Develop guidance for adoption of the modified PCI standard to address short-, medium-, and long-term strategies.
- Work towards development of a new Tier 3 pavement preservation measure that will allow for a more direct, accurate measurement of structural adequacy for pavements.

Travel Time-Based Metric

- Move towards utilizing a single data source with direct measurement.
- Conduct research on matching of traffic volume data to vehicle probe data and implications of different approaches.
- Provide oversight on progress made by the states in designing their data collection programs to support congestion/mobility monitoring, and provide technical support in the form of:
  - Providing access to national experts on measuring congestion.
  - Developing a "model" data collection program to support congestion/operations performance measures.
- Utilize the results of SHRP 2 Project L02, *Establishing Monitoring Programs for Travel Time Reliability*, and other SHRP 2 projects as technical support.

Congestion Cost

- The factors and relationships related to value of time, average fuel economy, and fuel cost should be determined annually with the help of FHWA.
- Other data issues and recommended solutions are the same as those indicated for "Travel Time-Based Metrics" above.

Reliability on the Interstate System

- Resolve the issues surrounding the collection of continuous travel time data, as noted under the "Travel Time-Based Metrics".
- In the longer term, conduct research to establish the linkages between activities and changes in outcome measures

Greenhouse Gas Emissions

- The Task Force would design and finalize the details of a process and working agenda to identify and implement GHG emission performance measures,
- Develop final consensus among states on GHG emission measure definition, and establish a schedule for Tier 1 implementation.
- Track and document individual state and regional best practices to serve as guidance for the development and implementation of the national measure.

3.2 TIER 3 MEASURES

Structural Adequacy of NHS Bridges

- Develop a proof-of-concept that demonstrates the measure's calculation using available NBI data to:
  - Reach consensus on the relative weight of each of the existing NBI ratings in terms of overall structural adequacy; and
  - Reach consensus on thresholds that could be used to convert the resulting structural adequacy index to a good/fair/poor scale.
- After Pontis is updated to include revised AASHTO Commonly Recognized (CORE) Bridge Elements after several years, consider using bridge element level data as the main data source for this measure.

Incident Management on NHS Routes

- Utilize the ongoing incident management performance measures effort by FHWA (Office of Operations), in conjunction with the National Traffic Incident Management Coalition, as a basis for this measure.
- Determine data collection responsibilities for each state or urban area.
- Assemble best practices for data collection, management, and reporting to serve as a guide for practitioners.

Work Zone Closure

- Utilize the ongoing work zone performance measures effort by FHWA as a basis for this measure.
- Work towards developing a new data collection effort in order to develop and report this measure.
- Assemble best practices for data collection, management, and reporting to serve as a guide for practitioners.

Stormwater Runoff

- Design and finalize the details of a process and working agenda to identify and implement stormwater emission performance measures.
- Develop a phased approach to stormwater measurement, enabling DOTs to develop a nationwide baseline approach to measurement based on current DOT data collection capabilities, and transition to more robust approaches as the state of practice evolves; this will also enable DOTs to respond to the new NPDES rule anticipated in the summer of 2012.

- Commission a research study to prepare a final set of options for stormwater measures and convene a practitioner workshop to review and provide input on these options prior to developing a final recommended approach.
- Provide guidance and technical support through AASHTO's Center for Environmental Excellence, the North Carolina State Center for Transportation and Environment, and by FHWA and the EPA.
- Conduct research to advance modeling and data collection techniques, test the effectiveness of individual measures in contributing to watershed health, and assess the utility of the selected measure(s) in supporting DOT decision making, regulatory compliance, and reporting.

Rural Highway Accessibility

- Design and finalize the details of a process and working agenda to identify and implement rural freight accessibility performance measures.
- Coordinate with the development of livability performance measures.
- Develop a phased approach to rural freight access measurement, enabling DOTs to develop a nationwide baseline approach to measurement based on current DOT data collection capabilities, and transition to more robust approaches as the state of practice evolves.
- Commission a research study to prepare a final set of options for rural access measures and convene a practitioner workshop to review and provide input on these options prior to developing a final recommended approach.
- Conduct research to advance data collection and statistical stratification and aggregation techniques, test the effectiveness of individual measures in identifying both measurable and perceived access, identify how investments in rural access are reflected in corresponding metrics, and assess the utility of the selected measure(s) in supporting DOT decision making, regulatory compliance, and reporting.

Livability

- Design and finalize the details of a process and work agenda to identify and implement livability performance measures, with consideration of the suggested steps outlined here.
- Lay out a process for selecting a measure (or set of measures), and an implementation process and schedule to be used to track livability.
- Create a guidebook for agencies that outlines details for each of the measures, including considerations for implementation, data sources, calculations, specifics on measure reporting (e.g., frequency and format), and any other requirements.

- Review research and findings on the validity of livability performance measures, identify gaps in the research, and propose additional research ideas to assist in moving livability first to the Tier 2 measure category, and ultimately to the Tier 1 measure category area.

3.3 LEADERSHIP AND PARTICIPATION

It is recommended that SCOPM serve as the coordinating body for these efforts and maintain a task force for each Tier 2 and 3 measure approved by SCOPM. These task forces will be responsible for:

- Conducting or synthesizing relevant research;
- Developing guidance that would accompany each measure as it moves towards Tier 1;
- Coordinating with other stakeholders, potential contributors, and other AASHTO committees in the technical development and definition of the measures; and
- Reporting progress on measures to SCOPM at least semi-annually.

Table 3.1 lists potential agencies and committees that could be represented on the tasks forces. Each agency provides a unique perspective to the measure formulation process. These recommendations should serve as the foundation for developing the task forces, but participation should be extended as necessary to other agencies or organizations. Task forces can also coordinate with other stakeholders or potential contributors not directly included on the task forces, as indicated in Table 3.1. The table also presents the relative level of effort and time required to move each measure to Tier 1: low, medium, or high.

As the coordinating body for these efforts, SCOPM would continue to be responsible for consolidating the information from the task forces, vote on changes, deletions, or additions to the Tier 2 and 3 measures, and conduct outreach with the AASHTO board members and others.

Table 3.1 Task Force Leadership, Participation, and Coordination

Goal Area	Recommended Measure	Tier	Potential Task Force Participants (AASHTO Committees)	Potential Task Force Participants (Other)	Coordination with:	Relative Effort for Advancement to Tier 1
Safety	5 year moving average of the state number of serious injuries	2	• SCOPM • Standing Committee on Highway Traffic Safety	• Governors Highway Safety Association • International Association of Chiefs of Police	• FHWA • NHTSA	Low-Medium
Pavement Preservation	Structural adequacy on NHS	2	• SCOPM • Standing Committee on Highways, Subcommittee on Maintenance	• FHWA Office of Asset Management		Low-Medium
Bridge Preservation	Structural adequacy of NHS bridges	3	• SCOPM • Standing Committee on Highways, Subcommittee on Bridges and Structures	• FHWA Office of Bridge Technology • FHWA Office of Asset Management		Medium
Congestion/ Operations	Travel time-based metric	2	• SCOPM	• FHWA Office of Operations • FHWA Office of Highway Policy Information		Low
	Congestion cost	2	• SCOPM	• FHWA Office of Operations		Low
	Reliability on the Interstate system	2	• SCOPM	• FHWA Office of Operations		Low
	Incident management on NHS routes	3	• SCOPM	• FHWA Office of Operations • National Traffic Incident Management Coalition (NTIMC)		Medium
	Work zone closure	3	• SCOPM	• FHWA Office of Operations	• National Transportation Operations Coalition	Medium

Goal Area	Recommended Measure	Tier	Potential Task Force Participants (AASHTO Committees)	Potential Task Force Participants (Other)	Coordination with:	Relative Effort for Advancement to Tier 1
Environment	GHG Emissions	2	• SCOPM • Special Task Force on Climate Change • Standing Committee on the Environment • Air Quality Subcommittee • Standing Committee on Planning		• FHWA • FTA • EPA • State DOT leadership • State resource and energy agencies	Medium
	Stormwater runoff	3	• SCOPM • Standing Committee on Environment • Standing Committee on Planning • Standing Committee on Design	• FHWA • EPA • Federal Resource Agencies	• State resource agencies • Researchers and NGOs with expertise in water quality, watershed management, and stormwater management	Medium
Freight/Economic Competitiveness	Rural highway accessibility	3	• SCOPM • Others as appropriate	• Others as appropriate	• NADO	High
Livability	*Definition to be identified and draft measures proposed*	3	• SCOPM • Standing Committee on Planning • Standing Committee on the Environment	• Representatives from other partner agencies and stakeholders	• HUD • EPA • MPOs	High

3.4 RECOMMENDED TIMING

While Tier 2 and Tier 3 measures may not need formal approval from the AASHTO Board before being moved into Tier 1 measures, it is recommended that substantial input be obtained from the Board on the measures currently being recommended by SCOPM as Tier 2 and 3. This input will help ensure that SCOPM is moving forward with measures that the AASHTO membership finds useful, and may help identify other measures that could be included.

It is recommended that this occur annually at the AASHTO Annual Meeting.

Soon after this vetting, SCOPM should develop a task force for each Tier 2 and 3 measure. Within 6 months after approval of the measures, the task forces should have a prioritized list of action items that will be conducted over the upcoming year.

4.0 Measure Updates

The process for modifying the matrix of measures will be an AASHTO-driven process, in consultation with FHWA and other stakeholders. Each SCOPM-designated task force will lead the process for its respective measure or goal area, reporting back regularly to the larger SCOPM membership. Three elements to consider include:

- **Modification of elements or definitions of existing measures.** It is the function of each measure task force to continue the advancement of its assigned measure or measures. These groups should report back to SCOPM on a regular basis. SCOPM should discuss and vote on specific defining features of the measure as they are vetted by each task force, either to add greater definition to a measure or modify pre-existing elements of the definition. This may include items such as system or geographic extent of a measure, calculation process, data sources, reporting format, and target-setting procedures. This also includes determining whether a measure meets the criteria necessary for being moved into the next Tier.
- **Removal of existing measures.** Suggestions for measure removal may come from a particular goal area task force, SCOPM, the AASHTO membership, or outside agencies such as FHWA. Nevertheless, it is the responsibility of SCOPM to discuss the measure among its members and vote on whether it should be removed from the matrix. Reasons for removal could include overlap with other measures, changes in national priorities, or an inability to reach consensus or to advance a measure over a long period of time.
- **Addition of new measures.** This process reflects that which SCOPM used to originally develop and vet the matrix. Suggestions for new measures may come from a particular goal area task force, SCOPM, the AASHTO membership, or outside agencies such as FHWA. Nevertheless, it is the responsibility of SCOPM to discuss the measure among its members, further define it, and vote on whether it should be added to the matrix. If the measure is selected, the same criteria identified in Section 1 should be used to determine in which Tier the measure should be placed. Measures should then follow a general process for advancement that follows that for the corresponding Tier in the previous sections, with the first step being the development of a task force to further define the measure, advance it, and determine a more specific plan for implementation.

As new Tier 1 measures are adopted or as the existing tier 1 measures are updated, the collection protocol described in Section 2 will need to be updated. Once a measure has moved into Tier 1, it should follow the processes for adoption outlined above.

5.0 Technical Support Program

5.1 OUTREACH AND JOINT ACTIVITIES

At the September 2010 *National Forum for Performance-Based Planning and Programming* the several proposals were suggested for continuing outreach. These suggestions can be applied to the development of national level performance measurement in several ways:

- **Synthesize existing practice, literature, institutional relationships, and other research/policy efforts by creating an on-line repository for best practices.** This process can begin immediately with minimal effort, leveraging existing AASHTO, FHWA, and other websites focusing on performance management that already exist. At least one individual should be responsible for the website, ensuring it stays current in order to be a useful tool.
- **Increase coordination among governing entities to establish a cohesive performance management process, including collaboration across Federal agencies, state DOTs, MPO, transit agencies, and nontransportation partners on strategies to reach common transportation goals.** One element of this includes initiating a pilot study that incorporates a state DOT, MPO, transit agency, and rural organization to illustrate a regional implementation of an integrated performance management process and explore the institutional relationships between planning partners. This process has already been initiated through NCHRP, with the intent of conducting pilots in three different regions.
- **Provide Federal guidance to facilitate the necessary coordination, input, and collaboration among agencies.** This guidance should be provided by FHWA and FTA. FHWA has already begun developing a modular training program which defines the basic elements of performance management. These modules will be tailored to the appropriate agency type, the audience (i.e., senior management, staff), and the level of familiarity with performance management. The training will be useful for both senior officials, who may want to learn key aspects of a performance-based program; and agency staff, who may need to understand the details of developing a performance management program.
- **Continue the comparative measure effort to allow for effective comparisons across agencies.** NCHRP, with guidance from SCOPM, should initiate comparative measure efforts on Tier 2 measures similar to those

already conducted for safety, pavement preservation, and bridge preservation.

- **Conduct additional capacity-building peer exchanges to continue the discussion among organizations.** These should build on the success of the *National Forum*. These can be in the form of additional *National Forums*, with a similar set of participants and a similar high level program. However, the magnitude of such an event in terms of preparation and resources makes it challenging to hold an event more frequently than every two years. Between such *National Forums*, more targeted peer exchanges prepared and hosted by FHWA, FTA, and AASHTO can be held as part of the regular series of such exchanges already held by these organizations. Such peer exchanges can be more focused on specific elements of performance management, specific goal areas, or specific measures. Some should be policy-oriented while others should focus on technical aspects. SCOPM should be directly involved in the recommendations for these peer exchanges, as the necessary topics for capacity building should emerge from the ongoing work of the task forces.

5.2 MEASURE-SPECIFIC TECHNICAL SUPPORT

Table 3.1 outlines the suggested parties for leading technical support for each Tier 2 and 3 measure. Beyond general technical support, several measures have specific items that need to be more closely targeted through this technical support.

Ultimately, the task force for each measure should lead an effort to create a guidebook for agencies that outlines details for each measure, including considerations for implementation, data sources, calculations, and other relevant issues. This document will also provide specifics on measure reporting (e.g., frequency and format) and any other requirements. These guidebooks should follow a similar format to Volume 1 of this report, and will serve as an addendum as Tier 2 and 3 measures are ready to be moved to Tier 1.

Table 5.1 Measure-Specific Technical Support

Goal Area	Recommended Measure	Tier	Support Led by:	Specific Technical Issues to Address
Safety	5 year moving average of the state number of serious injuries	2	• FHWA • NHTSA • NCHRP	Consistent, accurate, and timely data collection
Pavement Preservation	Structural adequacy on NHS	2	• AASHTO • FHWA • ASTM	• Harmonization of distress measurement • Modification of the PCI standard • Adoption of the standard

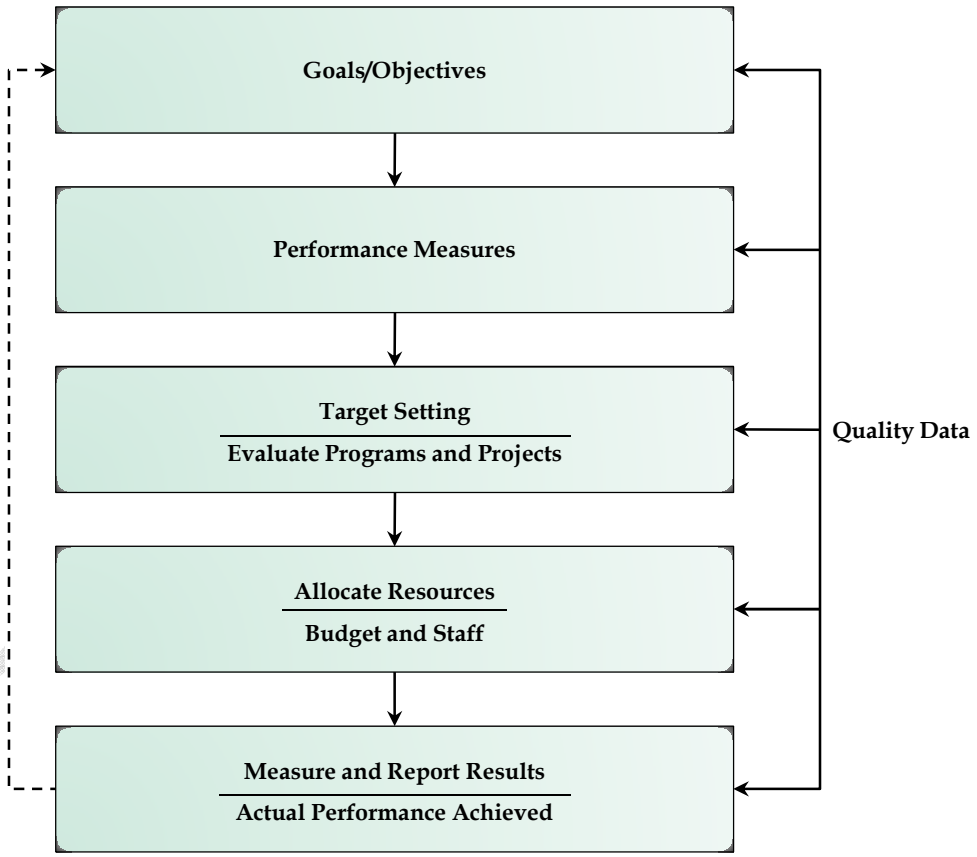
Goal Area	Recommended Measure	Tier	Support Led by:	Specific Technical Issues to Address
Bridge Preservation	Structural adequacy of NHS bridges	3	• Standing Committee on Highways, Subcommittee on Bridges and Structures • FHWA Office of Bridge Technology • FHWA Office of Asset Management	
Congestion/ Operations	Travel time-based metric	2	• SCOPM	Data collection
	Congestion cost	2	• SCOPM	Data collection
	Reliability on the Interstate system	2	• SCOPM	Data collection
	Incident management on NHS routes	3	• FHWA	
	Work zone closure	3	• FHWA • National Transportation Operations Coalition (NTOC)	
Environment	GHG Emissions	2	• AASHTO's Center for Environmental Excellence • FHWA • EPA	
	Stormwater runoff	3	• AASHTO's Center for Environmental Excellence • North Carolina State Center for Transportation and Environment • FHWA • EPA	Modeling and data collection
Freight/ Economic Competitiveness	Rural highway accessibility	3	• SCOPM	Measure requires further development before technical guidance can be determined
Livability	*Definition to be identified and draft measures proposed*	3	• SCOPM	Measure requires further development before technical guidance can be determined

5.3 INTEGRATING MEASURES INTO STATE PLANNING PROCESSES

Overview of the Performance Management Framework

In general, performance-based planning takes place within an overall Performance Management Framework, depicted in Figure 5.1, which is comprised of six basic elements:

Figure 5.1 Performance Management Framework



- **Establish Goals and Objectives.** Performance-based resource allocation decisions are anchored in a set of policy goals and objectives which identify an organization's desired direction and reflect the environment within which its business is conducted. For example, many state DOTs have well-defined goals for the transportation system, including infrastructure condition, level of service and safety, as well as goals reflecting economic, environmental and community values.

- **Select Performance Measures.** Performance measures are a set of metrics used by organizations to monitor progress toward achieving a goal or objective. The criteria for selecting measures often include:
  - Feasibility;
  - Policy sensitivity;
  - Ease of understanding; and
  - Usefulness in actual decision-making.
- **Identify Targets.** A target is a specific value for a measure that an agency would like to achieve. The following method is recommended for setting targets for the each measure:
  - Data-based classification of performance condition: develop a performance threshold table.
  - Link performance condition to varying investment levels: develop a investment chart.
  - Select specific target levels through a collaborative process: involve agency senior staff and performance area experts, stakeholders, elected officials and the public.
  - Track progress towards achieving the targets over time and refine data collection procedures.
  - Adjust targets over time based on financial and policy changes: targets can be set for both the short term and long term.
- **Allocate Resources.** The allocation of resources (time and money) is guided by the integration of the preceding steps into an organization's planning, programming and project development process. To the extent possible, each investment category is linked to a goal/objective, a set of performance measures, and a target. Specific investment proposals are defined in relation to specific targets. "Project prioritization" is a form of resource allocation.
- **Measure and Record Results.** The data for each performance measure must be regularly collected and periodically analyzed. The analysis should indicate how close the organization is to achieving its targets and identify the actions necessary to improve results. Many public and private sector organizations have tracking systems in place to monitor performance allowing senior staff to make periodic budget adjustments.
- **Create Data Management Systems.** "Good" data is the foundation of performance management. Effective decision-making in each element of the performance management framework requires that data be collected, cleaned, accessed, analyzed, and displayed. The organizational functions that produce these requirements are called data management systems. There are two key dimensions to creating and sustaining these systems. The two areas are equally important and must be synchronized within an

organization to ensure the generation and use of accurate, timely and appropriate data. The first area centers on the technical challenges associated with data systems, including development and maintenance of hardware and software, and the specifications for data collection, analysis, archiving, and reporting. The second area focuses on the institutional issues associated with data stewardship and data governance.

Integration into Existing State Programs

As part of the national level performance reporting outlined in this report, no state DOTs would be required to incorporate these measures into their existing planning and programming processes or to create new processes. However, agencies could choose to integrate the measures into their existing processes to complement what they currently report. The way in which the measure is integrated into the process depends on the agency's existing framework, and the level of maturity of that framework. Current processes can be grouped into three broad categories:

- State DOTs with existing, robust performance management processes.
- States DOTs with moderately developed performance management processes, which might be able to leverage the reporting formats and target-setting methods to increase the robustness of their processes, provide better information to decision-makers, and make clearer links to planning and programming.
- States DOTs without a performance management process or in the nascent stages of developing such processes, which might leverage the reporting of these measures to jumpstart performance management within their agencies. Utilizing the performance management framework as a guide, there are several steps these state DOTs can follow:
  - Align goals with the national goals. Agencies may have more goals, and specific objectives, that go beyond specifically what is defined by AASHTO.
  - Begin by selecting the measures in the national level program at a minimum, as these measures will already be reported. However, this initial set of measures alone is unlikely to be sufficient for comprehensive performance tracking and decision-making. Performance measures should be selected within the context of the performance management framework above, based on agency and stakeholder needs. Data availability and cost of additional data should also be a consideration: other measures that can be calculated with similar datasets already necessary for the Tier 1 measures could be an initial consideration. Measures currently in Tiers 2 and 3 should also be an initial consideration for this additional set of measures, though measures can and should be tailored to an individual agency's needs.

- Follow the target-setting processes recommended in Volume 1 to develop targets on the national level measures that are relevant, useful, and realistic for the state. If desired, the agency could use similar target setting methodologies for its other selected measures beyond the national ones.
- Tier 1 measure results will be reported according to the processes outlined in Volume 1. Agencies may want to consider developing an annual performance report (sometimes referred to an "attainment report") for internal agency purposes or for distribution to decision-makers and stakeholders. This report can include both the Tier 1 measures and other agency-specific measures, and allows an agency to incorporate a narrative that accompanies the results.
- Over time, the agency can make a clearer link between the measures and decision-making (e.g., planning and programming).

Several resources exist for helping an agency develop or refine a performance-based planning and programming process:

- **NCHRP 8-36(47), Effective Organization of Performance Measurement.** This study assessed how transportation agencies, particularly state DOTs, incorporate performance measurement functions within their overall organizational frameworks. The study report documents lessons learned for transportation organizations that are setting up new programs or adjusting and reorganizing existing programs. It identifies the most effective organizational attributes that contribute to a successful performance measure program. In addition to assessing a sample of governmental transportation organizations, information was drawn from the private sector and general management literature.
- **NCHRP 8-62, Transportation Performance Management Programs – Insight from Practitioners.** This research included an investigation performance management programs at state DOTs and other transportation agencies. It examines the state of the practice for developing performance measures, collecting data, and using these measures and data to direct long-term and day-to-day agency decision-making. The focus of the research is on using performance measures to improve communication, business management, and resource allocation and decision-making.
- **NCHRP Report 666, Target-Setting Methods and Data Management to Support Performance-Based Resource Allocation by Transportation Agencies.** The purpose of this research was to develop a comprehensive framework for performance management, to describe in detail the performance measure target setting process within the framework, and to identify and analyze the data management systems needed to support performance-based decision-making by state DOTs. Twenty case studies were conducted to assess leading practices in the public and private sector. Public sector studies include national, state, regional, and local governments,

as well as international examples from Japan and Australia. The final product of the research is an "Annotated Guide to Target-Setting and Data Management for Performance-Based Resource Allocation."