TRANSPORTATION ASSET MANAGEMENT PLANNING: A COMPARATIVE STUDY OF STATE DOTS TAMP REPORTS

by

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ABSTRACT

DHANANJAY TATYASAHEB THORAT. Transportation asset management planning: A comparative study of state DOTs TAMP reports. (Under the direction of DR. OMIDREZA SHOGHLI)

The transportation system of a country plays a vital role in supporting the overall growth of the nation. These transportation systems are a set of complex networks of different types of assets which continuously undergo deterioration at an uncertain rate. The Federal Highway Administration (FHWA) has been considerably proactive and robust in responding to the need of the times. State Departments of Transportation are asked to create regulatory TAMP (Transportation Asset Management Plan). The purpose of the TAMP report is to develop a systematic framework of the Transportation Management System to coordinate and manage the assets throughout the foreseeable future with the help of various tools considering the historical and predicted data by the state agencies. Each state is required to develop a risk-based asset management plan for the National Highway System (NHS) to improve or preserve the condition of the assets and the performance of the system.

This research work is based on a comparative analysis of the TAMP reports developed by the U.S. states - Florida, Tennessee, North Carolina, Pennsylvania, Utah, Illinois, Virginia and California. This analysis is aimed at establishing a thorough collection and comparison of the data acquired from the TAMP reports. The analysis is done on the basis of the criteria sheet which was developed based on the different components of a TAMP. Also, the current deterioration models used by the mentioned states will be compared with several other models in order to analyse the efficiency of the models. The effect of various impacting parameters contributing to the deterioration of

pavements is also analyzed in the form of a few IRI models. The results of the study will be helpful in building a link within the state agencies and collaborating towards the transportation system development mission.

Keywords: Risk-based, data-driven, deterioration model, Transportation asset management plan.

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CHAPTER 1: INTRODUCTION

Transportation agencies in the United States have a long history of building roads, bridges, transit systems, and other infrastructure and managing an expanding inventory of assets. However, over the past decade, there has been a growing awareness that current methods of transportation infrastructure management are inadequate to meet the demands of American citizens and industry. The US Department of Transportation's (US DOT) 2015 Conditions and Performance (C&P) report identified an $836 billion backlog of unmet capital investment needs for highways and bridges alone (FHWA and FTA 2017). A less prominent yet potentially far-reaching new technical planning requirement may offer a more comprehensive way to integrate cost-benefit considerations into the ways state and regional transportation agencies develop and update their project portfolios (Lew 2017).

Recognizing this need, the Moving Ahead for Progress in 21st century, MAP-21, act was brought into action by the government on 6th July 2012. Funding surface transportation programs at over $105 billion for fiscal years (FY) 2013 and 2014, MAP-21 is the first long-term highway authorization enacted since 2005. The FHWA has offered freedom to the state agencies throughout the process of TAMP development. Transportation agencies differ in terms of their needs and resources and in the complexity of their systems (FHWA 2017c). Therefore, there is a need to establish a common framework to develop a TAMP and make the decision-making process more straightforward for state agencies.

The development of deterioration models is one of the most important keys to workout an appropriate TAMP. An accurate model could guide the state agency layout precise and best-fit maintenance and investment strategies. There are several deterioration models proposed with multiple factors consideration (FHWA 2017a). The state agencies often find it difficult selecting an appropriate model parallel to the current conditions. There is a need to compare the available models and guide the agencies with a common link to relate to their respective needs.

The objective of this research is divided in two major parts. The first objective of this study is to compare the TAMP reports of few leading state agencies. A thorough gap analysis is expected which will help determine the differences of the various components of the TAMP report including:

a. Asset Condition
b. Data Collection
c. Performance Measures
d. Risk Management
e. Deterioration Models

The second objective of this research is to compare and analyze the different IRI models which are currently used by the state agencies of Mississippi, Louisiana, Indiana, and Dubai. These four models were selected as they are currently being used by the respective transportation agency. This analysis will be based on the IRI data fetched from the Long Term Pavement Performance Database. This will help to determine the direction of the deterioration model development and the scope of improvement.

CHAPTER 2: LITERATURE REVIEW

The accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. The ongoing costs associated with preserving the condition and performance of existing transportation assets are significant. Billions of dollars are spent each year by state and local government agencies to mitigate deterioration and repair infrastructure, so the transportation system can continue to support its users reliably, safely, and with minimal disruption. Just like maintaining a home or an automobile, performing the right preventative maintenance at the right time can significantly extend the service life and avoid costlier repairs in the long run. This has led to a need to efficiently manage transportation system investments which has ultimately directed to a recognition of the benefits of managing assets using a data-driven systematic approach, generally referred to as Transportation Asset Management

2.1 What is TAMP?

Transportation Asset Management Plans (TAMP) act as a focal point for information about the transportation assets, their management strategies, long-term expenditure forecasts, and business management processes. "TAMPs are an essential management tool which bring together all related business processes and stakeholders, internal and external, to achieve a common understanding and commitment to improve performance. It is a tactical-level document which focuses its analysis, options development, programs, delivery mechanisms, and reporting mechanisms on ensuring that strategic objectives are achieved. Each state is required to develop a risk-based asset management plan for the National Highway System (NHS) to improve or preserve the condition of the assets and the performance of the system. States must address pavements and bridges but are encouraged to include all infrastructure assets within the highway right-of-way in their risk-based asset management plan" (FHWA 2017c). Basically, all the US states are supposed to develop and present the enclosed submittal of TAMP report in accordance with 23 CFR Part 515. A state asset management plan shall, "at a minimum, be in a form that the Secretary determines to be appropriate and include (FHWA 2017c):

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

The performance-based program introduced in the Moving Ahead for Progress in the 21st Century Act (MAP-21) and extended under the Fixing America's Surface Transportation (FAST) Act intended to "*Provide a means to the most efficient investment of federal transportation funds by refocusing on national transportation goals, increasing the accountability and transparency of the federal-aid highway program, and improving project decision making.*" (FHWA 2017c). Both acts expect the states to develop a risk-based asset management plan for pavement and bridges on the National Highway System

(NHS) and all state routes. The purpose is to improve or preserve the condition of assets and the performance of the system, along with providing data and decision tools to support strategies to program projects that will help the state DOTs meet targets for asset condition and performance of the NHS consistent with the national goals. One must not misapprehend the TAMP as a fix for short-term, emergency situations. Rather, a TAMP is capable enough to guide the state DOTs not only on the day-to-day but decade-to-decade basis. The TAMP process when utilized effectively is a powerful budgeting and management methodology that can prevent major problems by prolonging the life-cycle of critical assets, while also plan investments in the transportation network.

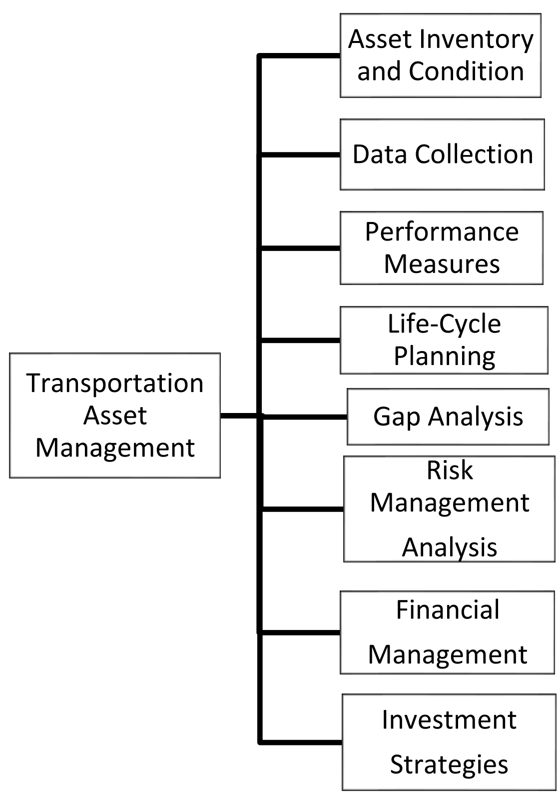


FIGURE 1. General format of a TAMP

2.2 Life-Cycle Methodology

The life cycle methodology is a comprehensive topic which provides a means to the most efficient investment of Federal transportation funds by refocusing on national transportation goals, increasing the accountability and transparency of the Federal-aid highway program, and improving project decision making. Basically, the life cycle methodology is the tool meeting the need developed by the asset management process. In simple language, the life-cycle methodology is the process of directing and managing the transportation assets right from the planning stage to the demolition or replacement phase. All the parallel processes required to achieve the common aim by the state agencies come under the scope of life-cycle methodology. The life cycle methodology is performed in various ways, out of which the LCP (Life-Cycle Planning) and LCCA (Life Cycle Cost Analysis) are most implemented.

The LCP is a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based on quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the life cycle of the assets at a minimum practical cost (Federal Highway Administration 2017). At a minimum, the LCP process shall include the following:

i. The State DOT targets for asset condition for each asset class or asset sub-group.

ii. Identification of deterioration models for each asset class or asset sub-group, provided identification of deterioration models for assets other than NHS pavements and bridges is optional.

iii. Potential work types across the whole life of each asset class or asset sub-group with their relative unit cost.

iv. A strategy for managing each asset class or asset sub-group by minimizing its life cycle costs, while achieving the State DOT targets for asset condition for NHS pavements and bridges.

The life cycle cost analysis (LCCA) is a data-driven tool that provides a detailed account of the total costs of a project over its expected life. Recognizing its benefit, several agencies have implemented LCCA programs and have successfully saved significant sums of money. LCCA was first introduced into the transportation decision-making process to help agencies determine the best pavement option for their project. Use of LCCA has been much more prolific in the private sector as there typically is a need to defend financial investment needs and decisions with an analytical tool, and owners often have multiple potential uses for available funds. But within the public sector, there is little incentive to use LCCA.

The analysis enables total cost comparison of competing pavement alternatives with equivalent benefits. LCCA accounts for relevant costs to the sponsoring agency, owner, operator of the facility, and the roadway user that will occur throughout the analysis period of alternatives (American Soceity of Civil Engineers 2014). The Caltrans uses life cycle cost analysis software, which is called RealCost (CALTRANS 2018). RealCost is a program developed by the Federal Highway Administration (FHWA) and was chosen by Caltrans as the official software for evaluating the long-term cost effectiveness of alternative designs for new and existing pavements. The main difference between the LCP and LCCA process is the scope of system. The LCP process is network level based while the LCCA process is project level based.

2.3 Asset Inventory and Condition

FHWA requires that a state's TAMP include a summary listing of NHS pavements and bridges, including a description of asset condition. The portion of the TAMP essentially includes the quantitative and qualitative data of the pavements and bridges in the state. The data can be current as well as from the past. Effective and appropriate data collection methods are implemented to obtain the current data and historic data to facilitate planning and to ensure compliance with the FHWA standards. The qualitative aspect of the assets is measured in accordance with the classification recommended by the FHWA i.e. good, fair or poor. This data keeping helps interpretation of the current status of the development carried out by the state DOTs. Also, the graphical trends traced form the data collected can help in deciding the future actions (Dong 2011).

In addition to providing inventory and condition data, states must also have documented procedures for collecting, processing, storing, and updating inventory and condition data for NHS pavement and bridges. The performance measures of the pavements and bridges can be defined independently by the state DOTs. This performance data keeping helps predict future needs, allocate funding, and schedule projects. The condition of the assets should be monitored after regular interval of time. The transportation assets are classified in three types: NHS, SHS, and local. Roadways on the NHS are defined by FHWA to be important to the national economy, defense, and mobility. It may include: Interstates, Principal arterials, the Strategic Highway Network

(STRAHNET), major strategic highway connectors, and Intermodal connectors. While, all the state owned, and managed assets are classified as State Highway System (SHS) routes. The locally owned are known as non-SHS. Some states voluntarily develop the TAMP analysis procedures for the other assets like drainage and Automated Transportation Management Sytems (ATMS) devices. ATMS devices include traffic management devices like traffic signals, CCTV, communication switches, walls, barrier, signs, pipe culverts, pavement markings, rumble strips, fences, or cattle guards.

2.4 Data Collection

The data collection process plays a vital role in maintaining the record of the inventory and performance of the assets. The goal is to maintain precise data of the assets for years to come, and the procedures required by the TAMP dictate the efficiency and reliability of data. Different state DOTs have different data collection processes. The advancement in technology has helped the process become more precise and easier to implement. Nowadays, various factors which may cause substantial changes in the data can be considered to enhance the clarity and conciseness of the data. It helps decrease the complexity of the data perhaps helping the future use of the same. The frequency of the data collection should be frequent enough to update substantial changes in the data.

Automated data collection process is the solution for efficient and frequent data collection. The process involves the combination of Continuous Digital Imaging and Automated Crack Detection technology (UTDOT 2018). The task is carried out by a Pavement Condition Survey Van which is mounted with advanced technology capable enough to collect of the pavement profiles, smoothness, distress and images (CALTRANS

2018). Some states use line scan sensors which provide faulting and rutting measurements as well as International Roughness Indices (IRI) of the pavement (NCDOT 2018).

For bridges, inspections are carried out by a registered inspector. The inspection is classified as regular and specialty inspection (FHWA 2017b). During a regular inspection, all the structural members of the deck, superstructure and substructure of the bridge are inspected. All the bridges with the need for specialized requirements are inspected during the specialized inspection. CALTRANS collects and maintains all this data with the SMART (Structural Maintenance Automated Report Transmittal) bridge management system. This compiled data is submitted to the FHWA (CALTRANS 2018).

The data collection process for drainage is well structured by CALTRANS, as it is the one of the few DOTs to take an initiative to include drainage systems in the TAMP report. Starting in 2005, Caltrans has been proactive enough to identify every drainage asset with a unique number. It is then assessed and inspected to feed the growing database which later helps to line up the asset for maintenance. The Culvert Inspection program plan reflects the completion of the inventory of drainage assets by the year 2027 (CALTRANS 2018). Subsequently, a TMS inventory database is used to track all TMS assets. It helps the designer to identify and utilize appropriate replacement cost estimates, as well as compare options such as costs of new construction. The most cost-effective solution can be determined. Priorities for the required maintenance are determined by evaluating the start date of the asset.

The frequency of the data collection process plays an important role in deciding the precision and validity of the data. As the transportation assets are used on a continuous basis, heavy traffic and fluctuating weather lead to unpredictable changes in the performance of the asset (Pierce, et al. 2013). Therefore, temporal and regular data collection frequency is suggested to be maintained in order to keep the data updated. Ideal frequency for the data updating process is annual.

2.5 Performance Measures

The performance measures are the predefined standards set by the states and FHWA to measure the condition of the asset. The states are free to define their own measures while they are following the FHWA minimum standards. The performance measures help to determine the condition of the asset in all the time phases – past, present and future (through deterioration models). FHWA recommends the state to follow the measures to make sure that the assets are performing well as compared to the past conditions and, also, appropriate actions are planned to maintain or enhance the performance in the future. Many states utilize asset management tools for pavements and bridges, coupled with a thorough reporting and review process to ensure systemwide performance meets target levels.

I. Pavements

Pavement behavior and performance is highly variable due to many factors, such as pavement structural design, climate, traffic, materials, subgrade, and construction quality. These factors contribute to changes in pavement performance that are reflected in the results of a pavement condition survey. The FHWA aids the state agencies in keeping the data variability lower to keep the accuracy level higher. The 'QM Practical Guide' is developed by the FHWA regularly to keep the performance maintenance procedures up to date. The 'QM Practical Guide' focuses on QM processes―including quality control (QC) and acceptance procedures―and the roles and associated responsibilities of both the agency and, when applicable, the service provider. It describes in detail the concepts and essential procedures of an effective QM plan and how they relate to the final quality of the data (Pierce, et al. 2013).

Pavement performance measures required for FHWA reporting include four distress components (PDOT 2018):

- International Roughness Index (IRI) – Quantifies how rough the pavement is by measuring the longitudinal profile of a traveled wheel track and generating a standardized roughness value in inches per mile.
- Cracking – Measures the percentage of pavement surface that is cracked.
- Rutting – Measures the depth of ruts (surface depression) in bituminous pavement in inches.
- Faulting – Quantifies the difference in elevation across transverse concrete pavement joints in inches.

These distress measurements translate to good, fair, or poor condition scores. Table 1 summarizes the pavement condition metrics for IRI, cracking percent, rutting, and faulting.

TABLE 1. Pavement condition metrics for distress measurements (FHWA 2017b)

RATING	GOOD	FAIR	POOR
IRI	<95	95-170	>170
Cracking Percentage	<5	CRCP: 5-10 Jointed: 5-15 Asphalt: 5-20	CRCP: >10 Jointed: >15 Asphalt: >20
Rutting	<0.20	0.20-0.40	>0.40
Faulting	<0.10	0.10-0.15	>0.15

IRI and cracking apply to both bituminous and concrete pavements, while rutting is exclusively for bituminous and faulting is exclusively for concrete. A pavement segment is considered in good condition if all three of its distress components are rated as good, and in poor condition if two or more of its three distress components are rated as poor.

FHWA has recommended that no more than 5 percent of a state's NHS Interstate lane-miles be in poor pavement condition. If this threshold is not met, restrictions are placed on that state DOT's federal funding—specifically, National Highway Performance Program and Surface Transportation Program funds. FHWA has not established a minimum condition for NHS non-Interstate roadways but requires the state DOT to establish performance targets.

II. Bridges

The FHWA final rulemaking established performance measures for all mainline Interstate Highway System and non-Interstate NHS bridges regardless of ownership or maintenance responsibility, including bridges on ramps connecting to the NHS and NHS bridges that span a state border (FHWA 2017b). FHWA's performance measures aim to assess bridge condition by deriving the percentage of NHS bridges rated in good condition and the percentage in poor condition, allowing no more than 10 percent poor bridges by deck area on the NHS. The bridge performance measures are divided according to the components of the bridge: deck, superstructure, substructure and culvert. Separate bridge structure condition ratings are collected for deck, superstructure, and substructure components during regular inspections using the National Bridge Inventory Standards. For culvert structures, only one condition rating is collected (the culvert rating). A rating of 9 to 0 on the FHWA condition scale is assigned to each component. Based on its score a component is given a good, fair, or poor condition score rating. Table 2 shows the bridge condition rating system.

TABLE 2. Bridge condition rating system (FHWA 2017b)

RATING	GOOD	FAIR	POOR
Deck	≥7	5 or 6	≤4
Superstructure	≥7	5 or 6	≤4
Substructure	≥7	5 or 6	≤4
Culvert	≥7	5 or 6	≤4

A structure's overall condition rating is determined by the lowest rating of its deck, superstructure, substructure, and/or culvert. If any of the components of a structure qualify as poor, the structure is rated as poor. The FHWA recommends that no more than 10% of a state's total NHS bridges by deck area are poor (PDOT 2018).

2.6 Gap Analysis

The FHWA requires state agencies to establish a performance gap analysis process for transportation asset management plans. Specific requirements for the process are listed below (CALTRANS):

a. State agencies targets for the asset condition of NHS pavements and bridges, using FHWA's performance measures.

b. NHS performance gaps.

c. Alternative strategies to close or address the gaps.

As part of the gap analysis, states must compare current asset performance to target performance levels, but they may also compare projected asset performance to target performance to calculate an expected gap.

2.7 Deterioration Models

Highway pavement performance gradually declines with the increase of highway life and traffic load times (Yang, et al. 2016). Accurate pavement management systems are essential for states' Department of Transportation and roadway agencies to plan for cost-effective maintenance and repair (M&R) strategies. Accurate and efficient pavement deterioration models are an imperative component of any pavement management system since the future budget and M&R plans would be developed based on the predicted pavement performance measures (Tari, et al. 2015). Various models have been developed till date within the scope of three types:

a. Empirical

b. Probabilistic

c. Mechanistic-empirical

Empirical prediction models are typically simple performance models that are obtained from fitting curves to historic performance data. The Highway development and Management Tool (HDM-4) is an example of these models that is widely used for condition prediction and strategic planning of pavements at project and network level (Tari, et al. 2015). Probabilistic models are typically based on the Markov chain process and work with transition probability matrices to account for the probability of pavement condition transitioning from one state to another. MicroPAVER is one of the widely used tools, which uses this model. Mechanistic-empirical models are based on constitutive laws for mechanical characteristics of pavements such as stress-strain relationships associated with external factors like traffic loads. Eventually, future condition of pavements is projected using statistical models. One of the performance measures considered in these guidelines is International Roughness Index (IRI), used as a measure of smoothness in flexible pavements (Tari, et al. 2015).

International Roughness Index is a pavement performance indicator which reflects not only the pavement condition but also the ride quality and comfort level of road user (Abdelaziz, et al. 2018). The increase in pavement roughness leads to an increase in fuel consumption, vehicle maintenance and repair cost, greenhouse gas emissions and decrease in vehicle efficiency. It may as well results in traffic safety issues that could lead to millions of dollars' loss every year (T 2016). The World Bank developed the International Roughness Index (IRI) in 1980s which is defined as 'the accumulated suspension vertical motion divided by the distance travelled as obtained from a mathematical model of a simulated quarter-car traversing a measured profile at 80 km/h' (ARA 2004). Several studies concluded a robust correlation between serviceability and roughness (ARA 2004). Thus, many agencies consider roughness as a serviceability measurement over time. Due to the importance of IRI as a pavement performance indicator, many research efforts have been devoted to IRI modelling and predictions.

CHAPTER 3: METHODOLOGY

This study includes comparative research and summarization of the TAMP reports of different states of America identified as leading in the transportation management sector. Though the FHWA has developed and proposed a systematic format guiding the state agencies developing a TAMP report, complete freedom has been given to the agencies within specified rules and standards. Hence, wide range of formats can be seen in the TAMP reports. Thus, this comparative research study was necessary to identify the nuances of different processes and encourage the best possible way of managing transportation assets.

The method adopted in this research is divided into two parts: quantitative analysis through the criteria sheet and analysis of the deterioration models.

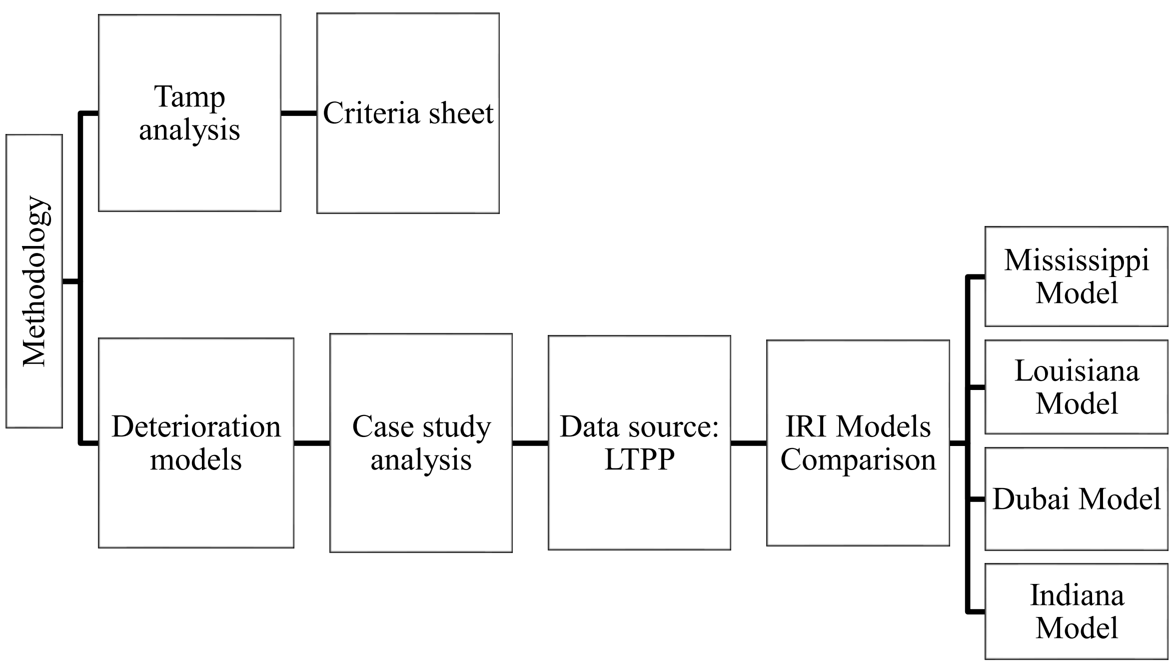


FIGURE 2. Methodology framework

3.1 Quantitative Analysis through the Criteria Sheet

The TAMP as mentioned earlier is a set of wide range of data including multiple aspects of the state transportation assets. To compare this vast data from different state agencies, a criterial approach is implemented in this study. TAMP reports of seven states: Tennessee, Pennsylvania, Illinois, North Carolina, Florida, Utah, Virginia, California are incorporated in the criteria sheet. The Criteria sheet is developed comparing all the components of any TAMP report. The criteria considered are:

a. Year the TAMP report was published
b. Approach
c. Asset inventory
d. Past conditions
e. Future predictions
f. Data collection process
g. Performance measures
h. Funding
i. Gap analysis
j. Deterioration model
k. Life cycle methodology
l. Investment strategy
m. Risk management

The sheet incorporates all the topics and sub-topics expected in a TAMP report. A simple quantitative approach will be implemented to comprehensively compare the data form the state agencies.

3.2 Analysis of the Deterioration Models

The deterioration models being one of the most important parts of the transportation management process, several approaches are developed and implemented to achieve the nearest and accurate results possible (PDOT 2018). In this study prime emphasis is given to the IRI performance-oriented models because many states have been using IRI as a primary function of pavement performance identification. Here, this study compares a few IRI models developed and used by some DOTs with the IRI data collected by LTTP.

a. Mississippi Model

The author (George 2000) developed this model in association with the Mississippi DOT and FHWA (George 2000). This roughness model incorporates the most recent overlay thickness and the resurfacing type of the pavement along with the Age, CESAL and MSN. The model with the five variables is given in the equation 1. The model was for the original pavements which yielded a coefficient of determination (R^2) of 0.35 based on 690 observations. The model followed the equation (1).

$$IRI = [3.5746 + Age^{0.1701}(1 + CESAL^{0.6972})]\ MSN^{-0.3438}\ TOPTHK^{-0.1313}\ RES^{-0.1056} \qquad (1)$$

Where

IRI - roughness, m/km

Age - Age of pavement since construction, years

CESAL - Cumulative 18-kip Equivalent Single Axle Load (ESAL) applied to the pavement (in the heavily trafficked lane), millions

MSN - Modified Structural Number

TOPTHK – Overlay thickness

RES – Resurfacing type

$$MSN = SN + SN_{SG}$$

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

$$SN_{SG} = 3.51 * log_{10}CBR - 0.85(log_{10}) - 1.43$$

Where

SN - Structural Number

a_i - ith layer coefficient

m_i - ith drainage coefficient

D_i - ith layer depth

CBR - California Bearing Ratio

b. Louisiana Model

This model was developed for flexible pavements for the state of Louisiana using regression analysis. which is based on LTPP data observations and it yielded coefficient of determination (R^2) of 0.47 based on 643 observations (Khattak, et al. 2013) and it is described by equations (2) as follows:

$$ln(IRI) = -0.902 - 0.2798 * \frac{1}{F_n} + 0.12078 * \frac{ln(CESAL)}{T_o} + 2.66 * 10^{-4}\,TI + 9.19 * 10^{-8} * CPI * t + \Delta \quad (2)$$

Where,

IRI - International Roughness Index, m/km

F_n - Functional classification

CESAL - Cumulative Equivalent Single Axle Load

T_o - Thickness of overlay

TI - Temperature Index, degree Celsius days

t - age of treatment, years

CPI - Cumulative Precipitation Index, cm-days

$\Delta = 4.388 + 0.723 \ln(SD_o) + 0.513 \ln(IRI_{pp})$

IRI_{pp} - Predicted of IRI for the previous year, m/km

SD_o - Initial standard deviation of IRI after treatment for each year during the life span of the treatment (0.99 m/km for this study)

c. Dubai Model

It is well known that the development of pavement roughness is a function of pavement age. The authors collected the IRI and pavement age data of more than 400 asphalt-surfaced pavement sections in Dubai Emirate (Suleiman 2003). Equations 3 and 4 represent the formulation for fast and slow lanes respectively.

$$IRI_F = 0.824 * exp(0.0539Age) \quad (3)$$

$$IRI_S = 0.769 * exp(0.0539Age) \quad (4)$$

Where

IRI_F - International Roughness Index (mm/m or m/km) in the fast lane

IRI_S - International Roughness Index (mm/m or m/km) in the slow lane

Age - Age of pavement since construction or last overlay, years

d. Indiana Model

$$IRI = (55 + 1.2 * Age + 0.00015 * AADT) * 0.0254 \quad (5)$$

Where,

IRI- Roughness in m/km

Age- Age of the pavement since last overlay

AADT- Average Annual Daily Traffic

TABLE 3. IRI model parameter checklist

Model	Age	Traffic	Temperature	Precipitation	Structural number	Overlay Thickness	Surface Type
Mississippi	✓	✓			✓	✓	✓
Louisiana		✓	✓	✓		✓	✓
Indiana	✓	✓					
Dubai	✓						

- **Case study selection process**

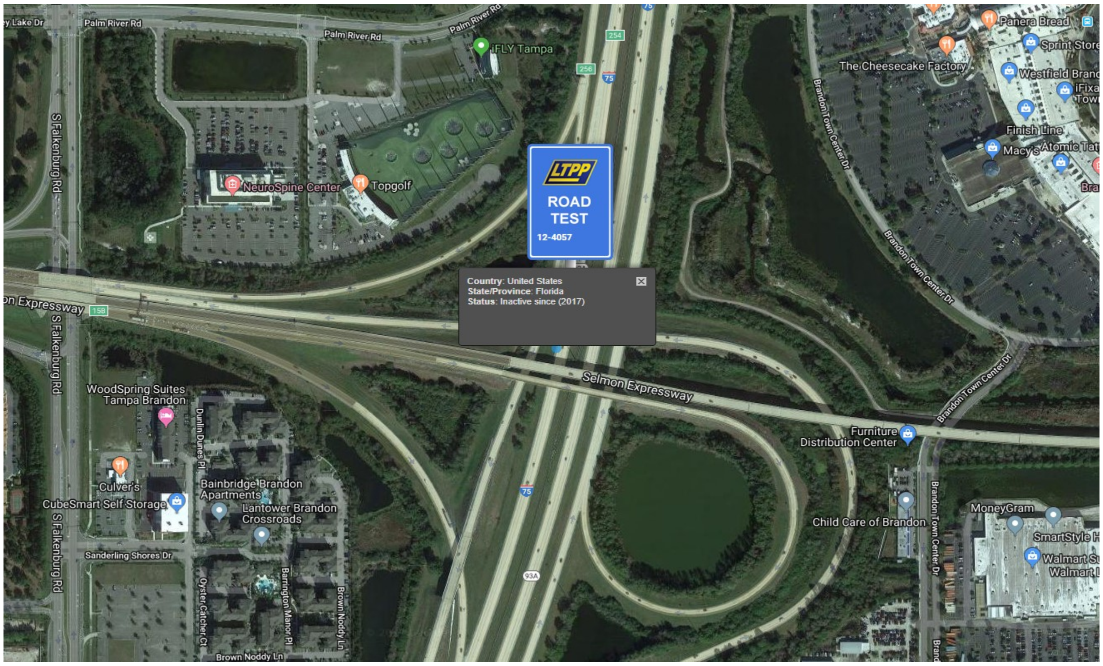
For this study different types of pavement with respect to variation in the nature and properties are selected based on the data obtained from the LTPP database. There, four case studies have been selected in the form of four pavements each from the states of Florida, Louisiana, Minnesota, and California. The selection criteria for the pavements were primarily focused on the difference in the climate zones all over the United States. Accordingly, following case studies are selected for this research from the LTPP database.

i. Hot Zone- Florida (12-4057)

ii. Cold Zone- Minnesota (22-0124)

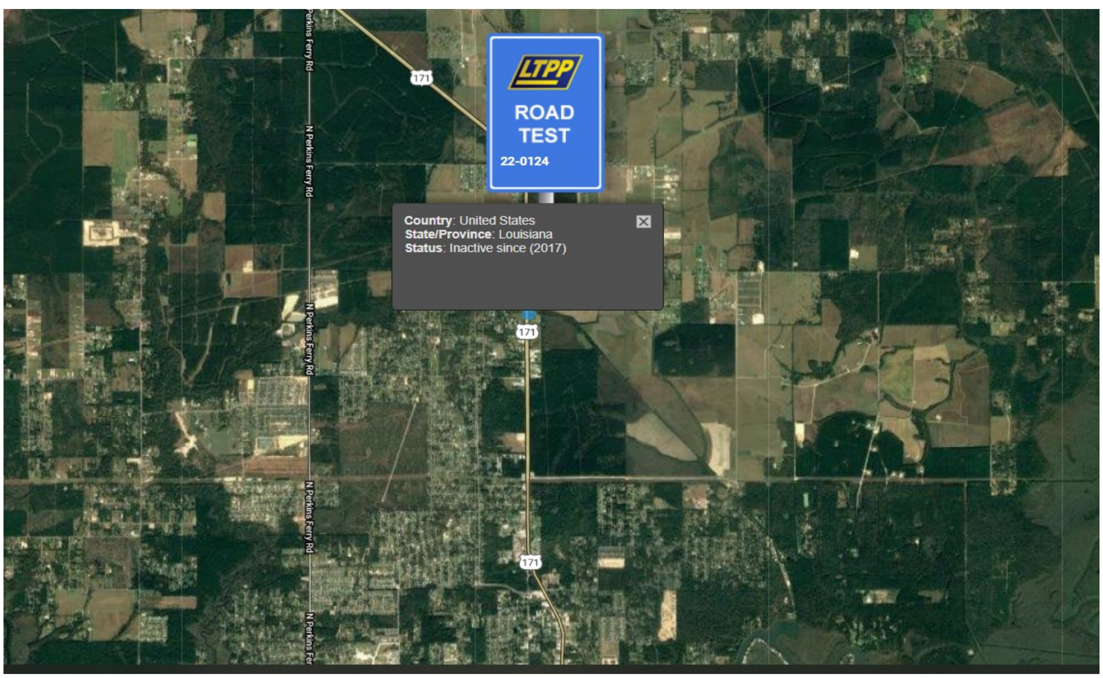
iii. Flood-Prone Zone- Louisiana (27-6251)

iv. Moderate Zone- California (06-7456)



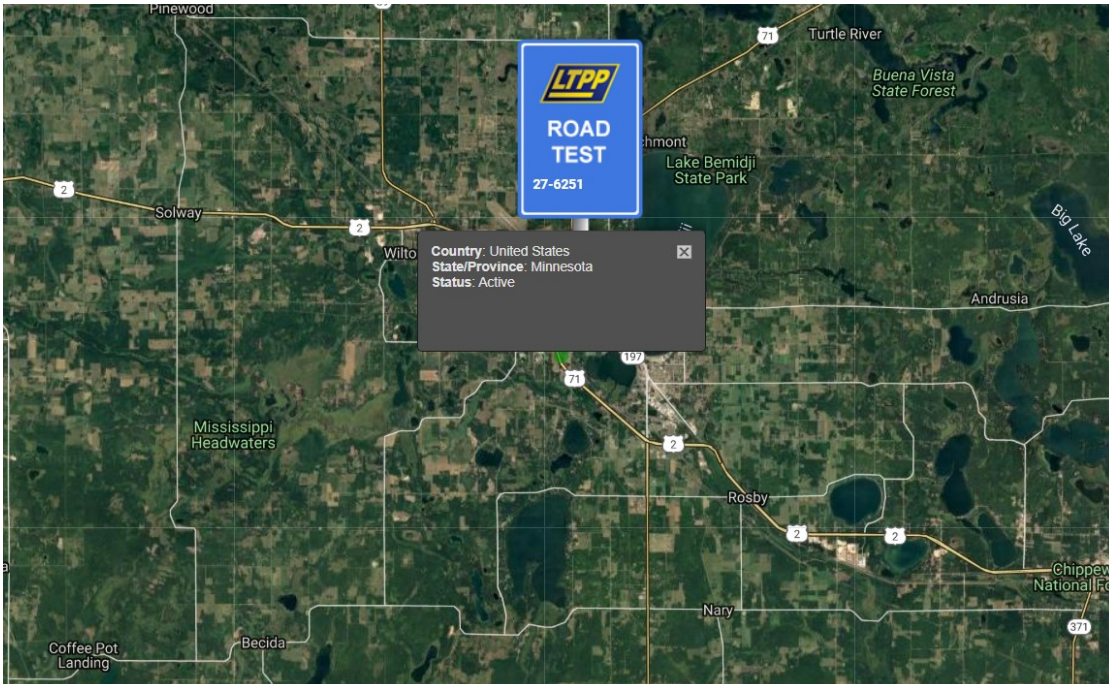
SOURCE: https://infopave.fhwa.dot.gov/Media/LTPPSectionMapping/Section-06-7456

FIGURE 3: Florida section (12-4057)



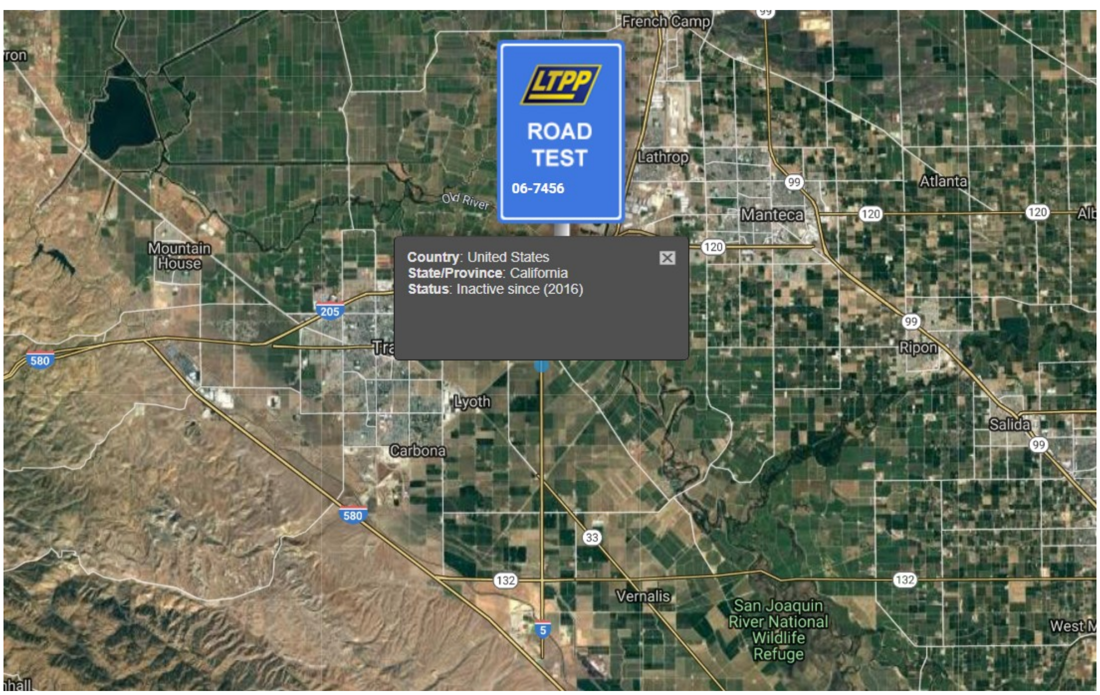
SOURCE: https://infopave.fhwa.dot.gov/Media/LTPPSectionMapping/Section-06-7456

FIGURE 4: Louisiana section (22-0124)



SOURCE: https://infopave.fhwa.dot.gov/Media/LTPPSectionMapping/Section-06-7456

FIGURE 5: Minnesota section (27-6251)



SOURCE: https://infopave.fhwa.dot.gov/Media/LTPPSectionMapping/Section-06-7456

FIGURE 6: California section (06-7456)

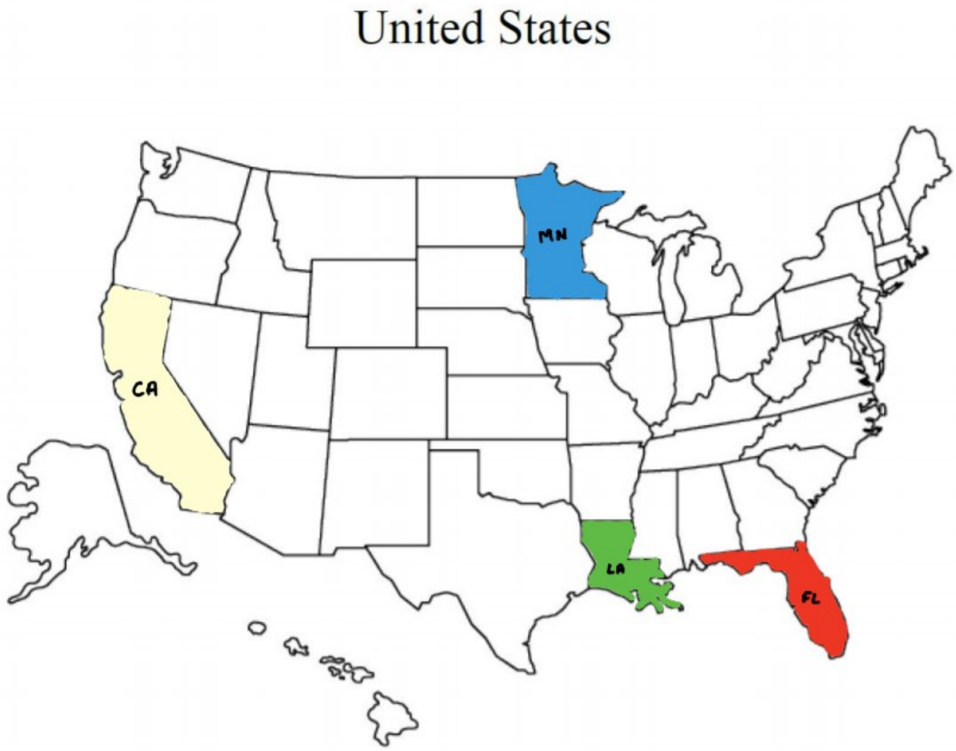


FIGURE 7: Case study

CHAPTER 4: RESULTS

The intensive study of the TAMP reports from the selected eight states led to the development of criteria wise comparison of the different contributing components. This comparison is mentioned in detailed structure ahead to recognize the different ways the state DOTs implement the overall transportation asset management.

4.1 Asset condition

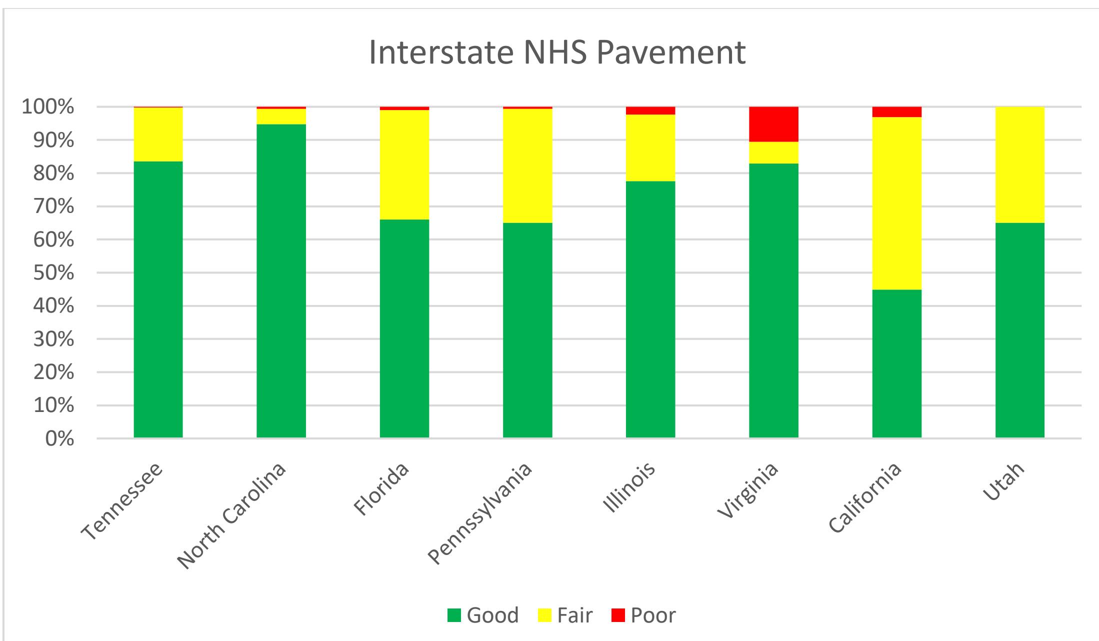


FIGURE 8: Interstate NHS pavement condition

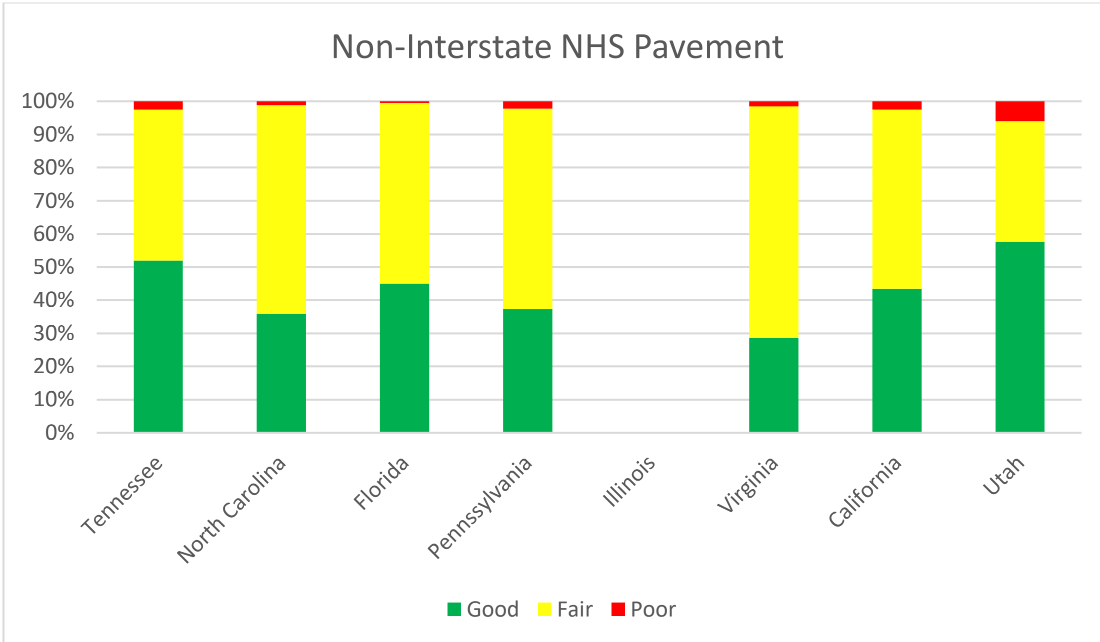


FIGURE 9: Non-Interstate pavement condition

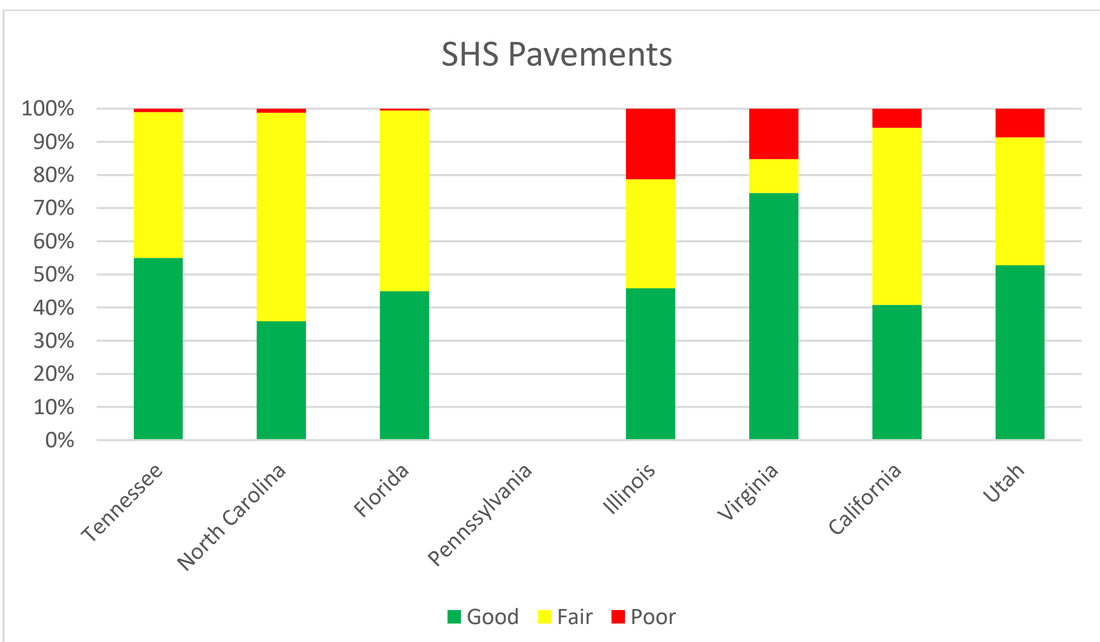


FIGURE 11: SHS pavement condition

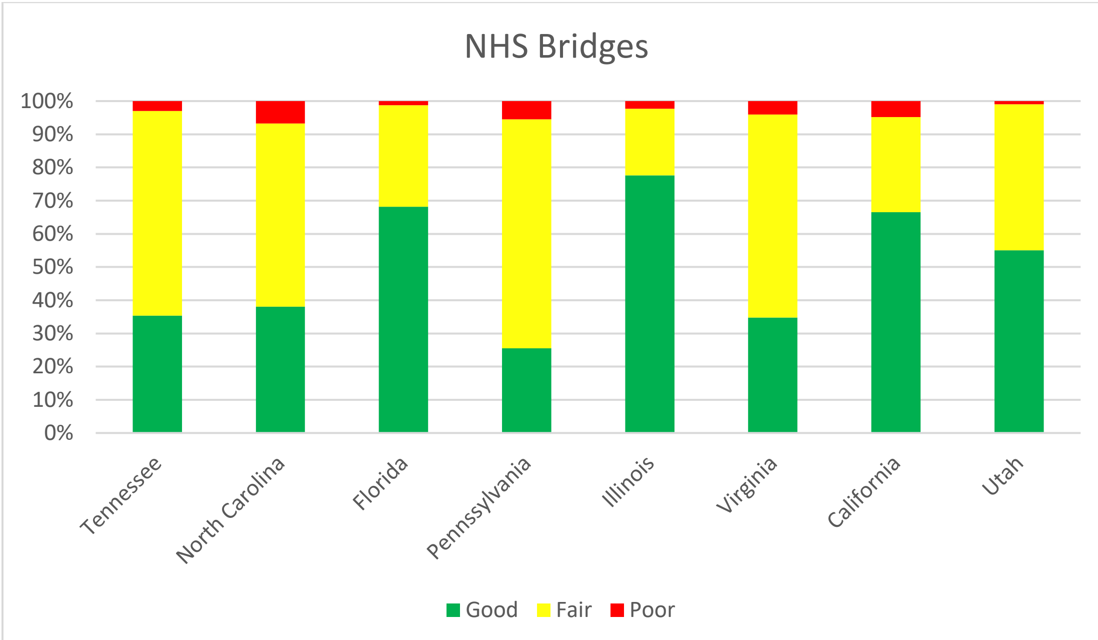


FIGURE 10: NHS bridge condition

4.2 Data collection process

TABLE 12: Data collection process

STATE	PROCESS DESCRIPTION
TENNESSEE	N/A
FLORIDA	N/A
ILLINOIS	**1. Pavement:** • Frequency: For Interstate Pavements – Annual For Non-Interstate – Two-year cycle • Procedure:

i. The data is collected and processed by a vendor using an automated data collection vehicle (DCV).

ii. CRS surveys are performed in each travel direction on divided highways and in one direction on all other routes.

iii. Downward-facing cameras are used to record pavement condition information and panoramic cameras provide visual references that are useful when viewing the images.

iv. Lasers are used to collect sensor data to determine rutting, roughness, and faulting measures.

2. Bridge:

- Frequency: Annual
- Procedure:

i. The agency conducts bridge inspections in accordance with the National Bridge Inspection Standards (NBIS) established by the FHWA and the IDOT Bridge Element Inspection Manual.

ii. NBIS inspections are conducted to ensure the safety of the public and to catalog accurate data reflecting each bridge's physical attributes and current conditions.

CALIFORNIA

1. Pavement

- Frequency: Annual
- Procedure:

i. Caltrans use the Automated Pavement Condition Survey (APCS).
ii. It comprises of a Pavement Condition Survey Van which is mounted with advanced technology capable enough to collect data of the pavement types, profiles, smoothness, distress and images.

2. Bridge:

- Frequency: Routine and Speciality Inspection.
- Procedure:

i. During the Routine Inspection all the structural members of the deck, superstructure and substructure of the bridge are inspected.
ii. All the bridges with the need of specialized requirements are inspected during the Specialised Inspection.
iii. All this data is collected and maintained with the SMART (Structural Maintenance Automated Report Transmittal) bridge management system.
iv. This compiled data is submitted to the FHWA.

3. Drainage:

- Starting from 2005, Caltrans have been resilient enough to identify every drainage asset with a unique number.

	• It is then evaluated and inspected to feed the growing database which later helps to prioritise the asset for maintenance. • The Culvert Inspection program plan reflects the completion of the inventory of drainage assets by the year 2027. **4. ATMS:** • A TMS Inventory Database is used to track all TMS assets.
NORTH CAROLINA	**1. Pavement:** • Frequency: Annual • Procedure: i. Both NHS and non-NHS routes are evaluated by the automated survey using high definition images for automated crack detection. ii. Line scan sensors provide faulting and rutting measurements as well as International Roughness Indices (IRI). **2. Bridge:** • Frequency: N/A • Procedure: i. For bridges a combination of Initial, Routine, In-Depth, Damage, Special, and Fracture Critical Inspections are

	carried out by NCDOT inspection teams, as well as by private engineering firms by contract. ii. The inspection report for these bridges includes condition ratings, photographs, maintenance needs, and recommendations for major improvements.
PENNSYLVANIA	**1. Pavement:** • Frequency: NHS Assets - Annual Non-NHS Assets - Two Year Cycle • Procedure: i. Condition data on PennDOT-owned pavements is collected by a contracted vendor with PennDOT performing quality assurance surveys using its own staff and equipment. ii. Survey data is collected using transverse and single-point laser profilers, as well as high definition video images, and the system generates semi-automated condition ratings for pavement distresses. iii. The pavement data is batch-uploaded into PennDOT's Roadway Management System (RMS) after sections are completed, data is post-processed, and QA/QC checks are performed. **2. Bridge:** • Frequency: Biennial • Procedure:

	i. Condition data on PennDOT-owned bridges is collected by certified bridge inspectors from both an in-house and consultant workforce. ii. Inspection frequencies may be extended for certain structures in good condition and are shortened for all structures in poor condition. iii. Inspection data is captured using an in-house mobile platform called iForms and is uploaded to PennDOT's custom Bridge Management System 2 database (BMS2). iv. BMS2 is integrated with PennDOT's SAP-based maintenance system and pushes recorded inspection issues to maintenance personnel.
VIRGINIA	**4.1 Pavement** • Frequency: Annual **4.2 Procedure** • The data collection process is carried out using Continuous Digital Imaging and Automated Crack Detection technology. • Camera equipped vans are used for capturing downward pavement images for crack detection as well as forward images. • For the determination of roughness and rutting of the pavement advance sensors are used.

UTAH	• UDOT maintains registers of many roadway assets through routine high-tech LiDAR scanning and maintenance inventories of the state highways. • These registers are used to track the quantity and some condition information of each UDOT asset. UDOT also maintains an extensive database of current unit bid item costs compiled from the advertisement o new construction projects. • This database is used to establish the replacement value of the quantified assets. • Additional sources of information, such as R.S. Means, are referenced to establish a value for specialty items that are not in the database. • A contingency amount is included in the replacement value of each asset to account for design, construction oversight, traffic control, and mobilization costs.

4.3 Performance Measures

As discussed in Chapter 2, each state DOT has a different approach to analyze and evaluate the performance of the pavements and bridges. Table 5 provides is a tabulated version of the details of the performance measures considered by the state transportation authorities.

TABLE 5: Performance measures

STATE	PROCESS DESCRIPTION
TENNESSEE	**1. Pavement** The TDOT uses two methods for pavement performance assessment: a. Pavement Quality Index (PQI) b. National Transportation Performance Measures (NTPM) a. PQI • TDOT collects pavement condition data and calculates a PQI for the Interstate, NHS State Routes and non-NHS State Routes. • PQI ranges from 0–5 (needs resurfacing to no need for maintenance). b. NTPM • Pavement is rated as per the metrics like roughness (IRI), fatigue cracking and faulting. • Each of these metrics are evaluated to determine the applicable performance rating (Good, Fair, Poor). **2. Bridge** • The TDOT uses two methods for bridge performance assessment: a. Using Structural Deficiency b. National Transportation Performance Measures (NTPM)

a. Structural Deficiency:

- TDOT conducts bridge inspections on all the publicly owned highway bridges in the state every two years except for federally owned bridges.
- TDOT uses the NBI rating for deck, superstructure and substructure.
- Culverts are assessed on the culvert score.
- The structurally deficient bridges are not unsafe, instead they are usually functionally inadequate.

b. NTPM

- Metric levels are used for the deck, superstructure, substructure, and culverts.
- Any metric that is evaluated as 7 or higher is in good condition.
- Any bridge metric that is evaluated as 4 or less is in poor condition and receives the designation as 'Structurally Deficient'.

FLORIDA

1. Pavement

- The performance measure and target for pavements on the SHS is: Ensuring at least 80 percent of the pavement on the SHS meets the Department standard.
- The department is working to establish targets for the FHWA performance measures for pavements on the NHS.

2. Bridge

- The performance measures and targets using the department's scale: 90 percent of SHS bridges in "Excellent" or "Good" condition measured by number of bridges.
- The Department will establish targets for the FHWA performance measures for bridges on the NHS.

ILLINOIS

1. Pavement

- Condition Rating Survey (CRS) values are used to determine the percentage of the highway system that is in the 'Desired Acceptable Condition'.
- The desired value of CRS for the Interstate roads should be 5.5 or greater, while for all other roads it should be or greater than 5.0.
- The Illinois Toll-way classifies its roadway conditions slightly different performance measures as shown in table 5:

Table 6: Condition Criteria

CRS	**Pavement Condition Category**
7.5-9.0	Excellent
6.6-7.4	Good
6.0-6.5	Transitional
4.5-5.9	Fair
1.0-4.4	Poor

	2. Bridge • Each of the major bridge components is evaluated using the National Bridge Index (NBI) rating. • The NBI rating scale ranges from 0 to 9 for a failed to excellent structure respectively.
CALIFORNIA	**1. Pavement** • Caltrans recommended and the Commission adopted the national performance measures for SHS pavements. • Most local jurisdictions in California utilize an alternative measure called the Pavement Condition Index (PCI). • PCI ranges between 0-100. **2. Bridge** • Caltrans uses the NBI system for the NHS bridge performance assessment. • The Caltrans TAMP uses the SHSMP data as the source of SHS bridge inventory and condition. **3. Drainage** • The condition assessment is based on a visual inspection of five attributes: a. Waterway adequacy b. Joints c. Material

	d. Shape e. Alignment • Each attribute is scored on a five-point scale from 0 to 4, where 0 is new and 4 is failure condition. **4. TMS** • Each asset is classified as in good or poor condition. • Good indicates the asset is operational and not obsolete. • Poor indicates the asset is obsolete or non-operational.
NORTH CAROLINA	• NCDOT uses the performance measures established by the FHWA. • NCDOT has established its own targets for the pavement and Bridges performance assessment known as State of Good Repair (SOGR).
PENNSYLVANIA	**1. Pavement** • PennDOT has adopted the FHWA standards of having no more than 5 percent of Interstate pavements rated as poor and no more than 10 percent of NHS bridges rated as poor. • PennDOT will establish targets for NHS non-Interstate pavement condition for the 2019 TAMP submission. **2.** PennDOT expects to establish condition targets for the remainder of the state's pavements and bridges that are not

part of the NHS and will publish these targets in future TAMP updates.

VIRGINIA

1. **Pavement**

- A measure known as Critical Condition Index (CCI) is used to assess the performance of the pavements by VDOT.
- CCI is derived according to the type of the pavement like:

a. For asphalt surfaced pavements LDR and NDR are used and CCI is defined as the lower of the two values.

b. The slab distress rating (SDR) is used for JCP pavements.

c. The Concrete Punchout Rating (CPR) and the Concrete Distress Rating (CDR) are collected for CRCP pavements.

Table 7: Pavement Condition Definition

Pavement Condition	**Index Scale (CCI)**
Excellent	90 and above
Good	70-89
Fair	60-69
Poor	50-59
Very Poor	49 and below

2. **Bridge**

- VDOT has adopted the national (FHWA) performance measures for the bridge performance assessment.

UTAH

1. **Pavement and Bridge**

- For the performance assessment, UDOT has adopted the FHWA recommended performance measures for pavements and bridge.

- To assure the system is adequately funded and not at any financial risk to be maintained per the Preserve Infrastructure strategic goal, the statewide condition target is to have 80% of the mileage rated Fair or Good.

2. ATMS

- As there are several components in ATMS system, the measure and target are tracked separately and reported monthly for each type of device and averaged into a composite score.
- The condition target is 95% of the system in operational condition.

3. Signal System

- The performance measure for the UDOT Signal system is the percent of signals that are in good or fair condition based on annual inspection of all electronics and physical infrastructure associated with signal systems.
- The target is that 95% of the statewide system is in good or fair condition.

4.4 Risk Management

1. Pennsylvania

- The methodology framework for risk analysis by the PennDOT is given as,

Risk = Likelihood x Consequence

- PennDOT uses two key dimensions as there are more than one factor or attribute to a given risk. Those two key elements are:

Unknown unknowns: It translates to detectability or the ability to detect the defect that may cause the risk.

Time: It refers to the confidence of a given predicted condition state in the future, as the accuracy of predicted condition can degrade into the future.

- PennDOT classifies risks in the following manner:
    a. Severe Risks: Funding shortage, project cost uncertainty, data issues and limited management systems.
    b. Very High Risks: Loss of Institutional Knowledge.
    c. High Risks: Increase in freight volume, construction quality and political influence on project selection.

2. Utah

- Risk is incorporated by the UDOT into asset management at two levels:
    a. Programmatic risk identification and assessment: Programmatic risk was assessed for each asset in each of the following four risk areas based on the probability of the risk happening and on the estimated consequences. Probability and consequence were assessed separately as high, medium, or low and a risk number assigned based on the risk matrix
        i. Financial - analysis of sustainable funding for performance goals
        ii. Information – availability and quality of data needed for long term management

iii. Operational – analysis of probability and impact of asset failure to the operation of the transportation system

iv. Safety – analysis of impact to public safety of asset failure or poor condition

b. System risk identification and assessment –

- UDOT completed a data driven system risk analysis of portions of I-15 and has initiated a second pilot project to refine the process and establish a standard workflow that can be implemented system wide.
- This approach is not intended to replace years of professional experience but to complement what has already been done and take into consideration an approach consistent with the FHWA's recommendations for evaluating Resilience & Durability to Extreme Weather events.

3. Florida

- FDOT classifies risks at three levels:

a. Agency and Program level Risks - At the agency and program levels, there is very minimal risk associated with funding shortages and cost increases which ultimately may result in service interruptions.

b. Pavement Asset level risks - For pavement assets, the Department has a robust, long-standing, pavement management program that has developed to the point that risks which may lead to service interruptions have been mitigated or minimized.

c. Bridge Asset level risks - The same as pavement assets, bridge asset risks associated with funding shortages and cost increases, which include material shortages.

4. North Carolina

- Classification:

a. Agency/Enterprise Risks

b. Programmatic Risks

c. Project/Asset Risks

- Methodology:

a. Establishing context

b. Identify risk

c. Analyze risk

d. Evaluate risk

e. Treat risk

5. Tennessee

- Classification:

a. Agency/Enterprise Risks

b. Programmatic Risks

c. Project/Asset Risks

- Methodology:

a. Establishing context

b. Identify risk

c. Analyze risk

d. Evaluate risk

e. Treat risk

6. Illinois

- Classification:

a. Agency risk

b. Program risk

c. Asset risk

- Methodology:

a. Manage risks

b. Monitor and Review risks

- Emergency Events:

a. Existing Process: A special project number for the emergency event is created by the Central Bureau of Operations and those geographical locations affected are required to track allocated resources by work activity code in response to the event using this special project number.

b. Assessment of Prior Emergency Events

c. Future Assessment of repairs due to Emergency Events

7. California

- Classification:

a. Enterprise Risk Management

b. Project Risk Management

c. Information Technology Management

d. Emergency Risk Management

e. Safety Risk Management

- Methodology:

State and local agencies in California have number of TAM-related risk mitigation programs. These programs deal with specific risk categories such as project risk, seismic risk, and climate change risk. They are as follows:

a. Safeguarding California

b. Project Risk Management Handbook

c. Seismic Safety Retrofit Program

d. Local Bridge Seismic Safety Retrofit Program

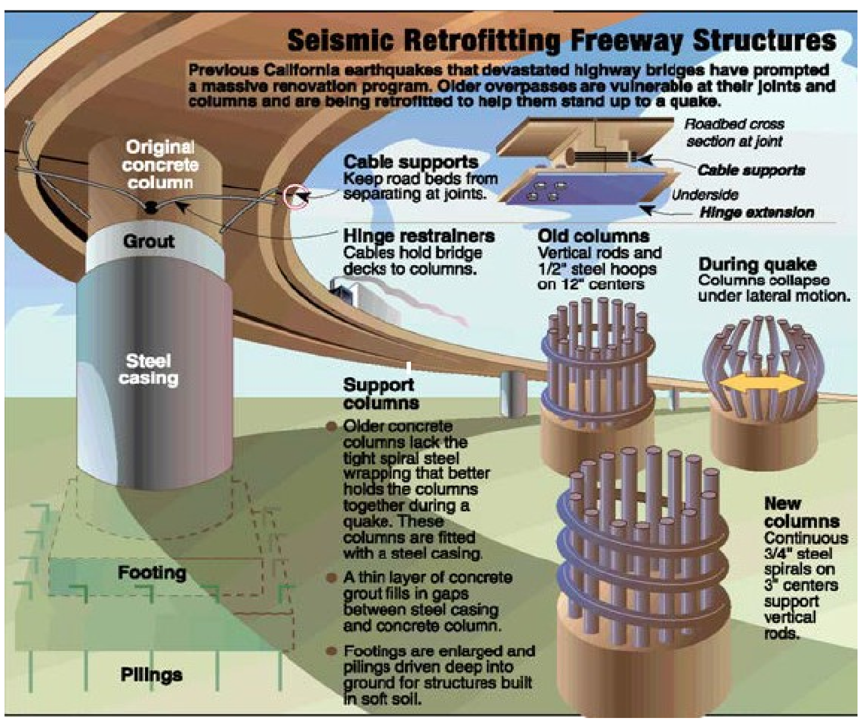
e. Local Highway Bridge Program

f. Local Bridge Preventive Maintenance Program

g. Highway Safety Improvement Program

h. Climate Change Resilience Pilots

i. Transportation Vulnerability Assessments with Criticality Scoring and Adaptation Plans



Source: Caltrans rev. 1/95

FIGURE 7: Seismic safety retrofit program

8. Virginia

a. Pavement Risk Management:

- The Primary focus of the risk management programs are in the following the areas:

a. Quality control of surface condition data collection.

b. Alignment of District project selection with network level investment strategy.

c. Field collection and review of planned and actual work accomplishment.

- All these programs follow the similar methodology of coming to the risk mitigation stage in a systematic manner:

a. Risk Statement

b. Risk Consequence

c. Risk Likelihood

d. Risk Management

b. Bridge Risk Management:

- Virginia's bridge risk mitigation program is guided by two primary concerns:

a. The likelihood of occurrence of a negative event or outcome.

b. The potential severity/impact of the negative event or overcome, were it to occur.

- The Scoring Formula is used by the VDOT to select bridges for funding which is called as "Priority Ranking System" for NBI SD bridges. The formula is based on five factors: Importance, Condition, Design Redundancy, Structure Capacity and Cost Effective.

- Scoring Formulae:

$$\textbf{Priority} = \mathbf{a(IF) + b(CF) + c(DRF) + d(SCF) + e(CEF)}$$

Where,

Max = 1.0 (highest priority); Min = 0.0 (lowest priority) a, b, c, d, e are weighing coefficients and Σ(a, b, c, d, e) = 1.0

The formula is based on five unitless factors, each of which may vary from 0.00 to 1.00:

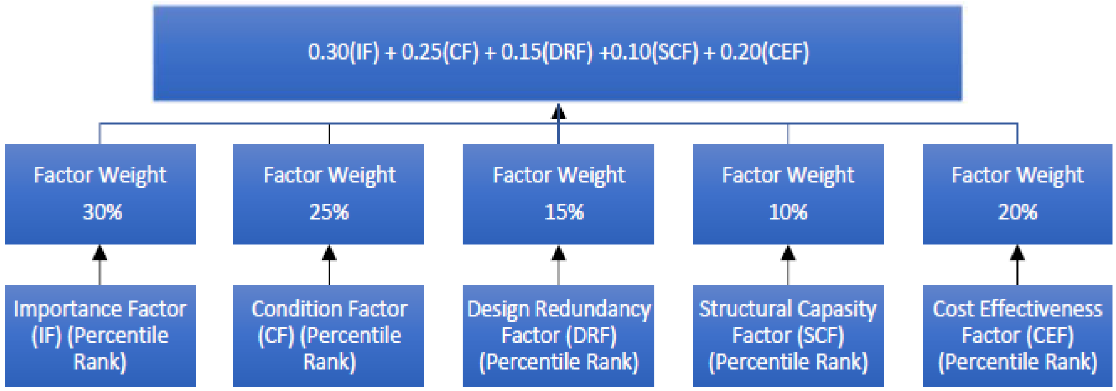


FIGURE 9: Factor weightage (Virginia Department of Transportation 2018)

Where,

IF = Importance Factor - measures the relative importance of each bridge to the overall highway network. Includes subordinate variables that consider Average Daily Traffic (ADT), Future ADT, Truck ADT, Effect of bypass (both distance and number of vehicles affected), Highway System, and Corridors of Statewide Significance

CF = Condition Factor – measures the overall physical condition of each bridge based on the condition of each individual element

DRF = Design Redundancy Factor - measures four important risk factors: Fracture Critical (redundancy), Scour Susceptibility, Fatigue, and Earthquake vulnerability

SCF = Structure Capacity Factor- measures the capacity of the structure to convey traffic, including the effects of weight restrictions, vertical clearance and deck width

CEF = Cost-Effectiveness Factor - measures the cost-effectiveness of the required work

4.5 Deterioration Models

The IRI models were applied to the pavement condition data obtained from the LTPP database and the predictions were compared with the measured IRI for years from 2000 to 2017. The results for different zones are obtained for a timeline as per the appropriate IRI data obtained from the LTPP database.

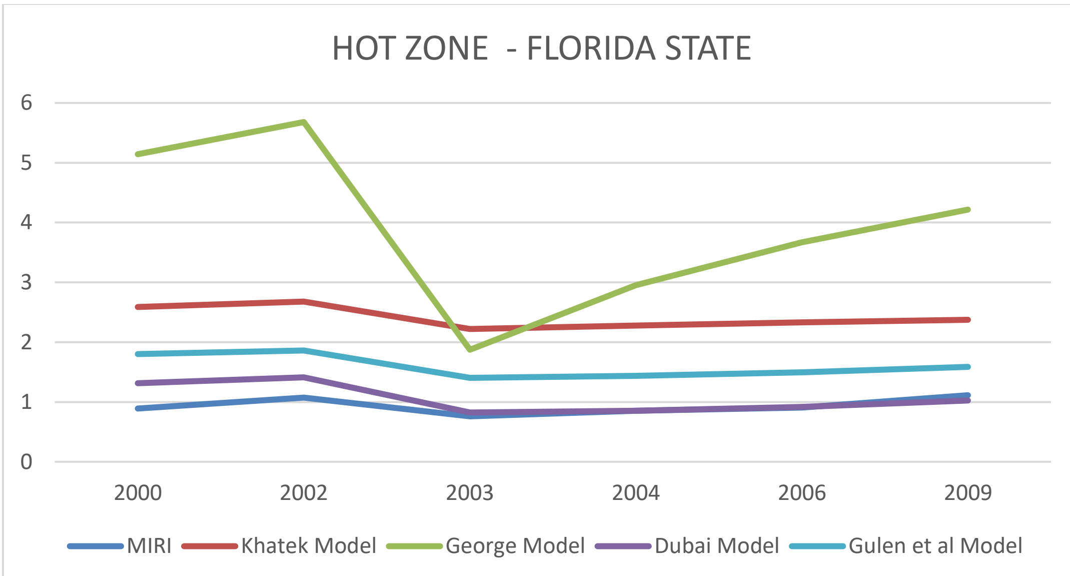


FIGURE 10: Result A

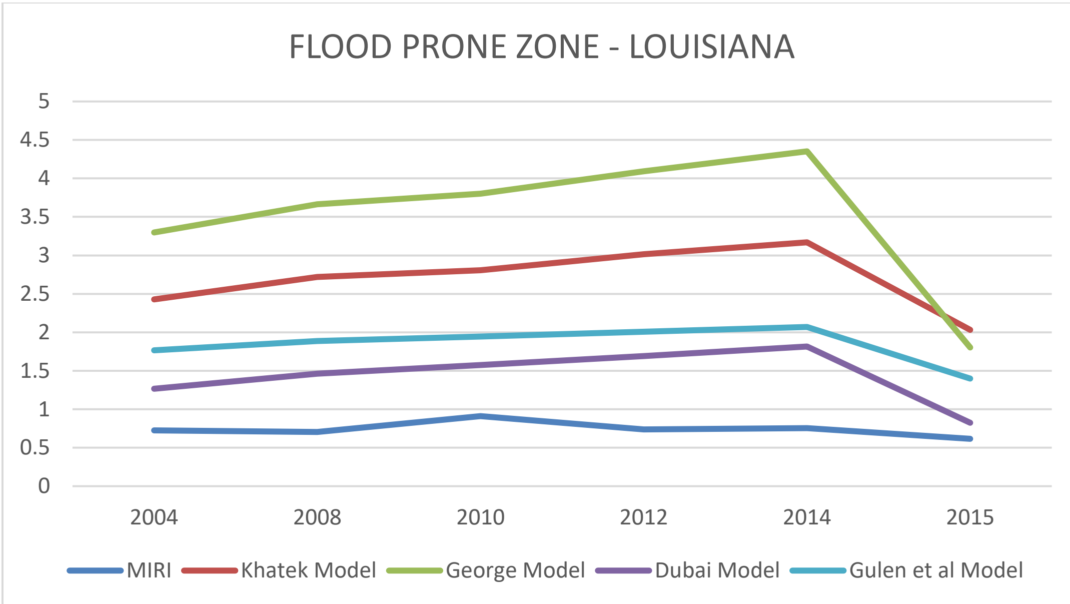


FIGURE 11: Result B

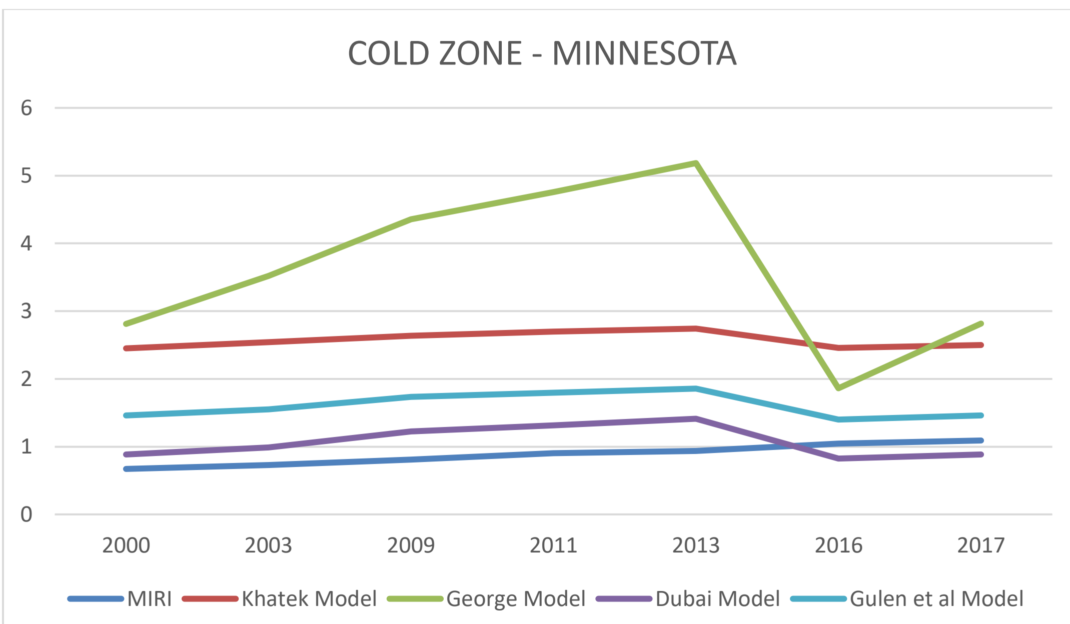


FIGURE 12: Result C

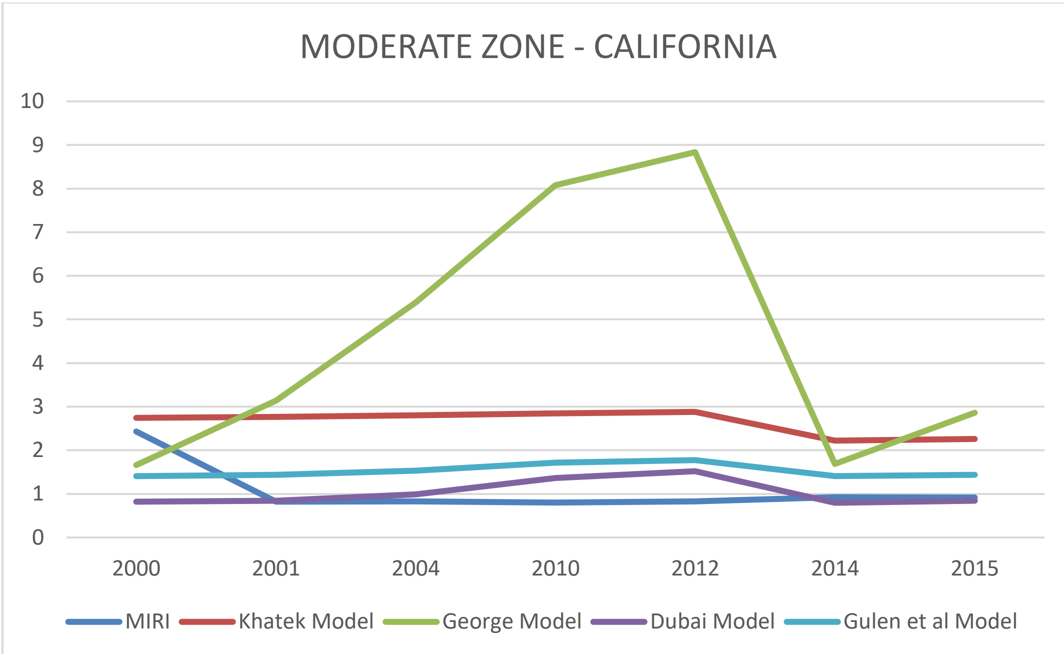


FIGURE 13: Result D

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1 Discussion

A. Asset condition

The asset condition bar chart is divided according to the type of the assets: Interstate NHS Pavement, Non-Interstate Pavement, SHS Pavement, and NHS Bridges. The difference in the current condition of the assets is readily evident. Most parts of the Interstate highways of North Carolina are currently in good shape as compared with the other states. Whereas, almost half of the California Interstate pavements are in moderate condition. The data for the Illinois state is not available in this case. The SHS pavements form the Virginia state are generally in better condition and most of it is in good condition. Reviewing bridge condition data, the Illinois state NHS bridges are in best condition as compared to the other states.

Though the pavement and bridge conditions are compared here in this study, the factor of inventory (number of pavements and bridges) is not considered. So, it is difficult to effectively compare the asset conditions of infrastructure components of the different states. The number of California state assets is greater than most of the other states, so, this could justify the low number of assets in good condition since it could be viewed as more challenging to maintain the condition of a larger inventory of assets.

B. Data collection process

It can be observed that the frequency of the data collection for almost all state agencies is around one to two years. But, the procedure of the process differs according to the management and finance of the agencies.

The advancement in technology has greatly impacted the data collection process for the better. Most of the state agencies are using Continuous Digital Imaging and Automated Crack Detection. The camera equipped vans are used to capture downward pavement images for crack detection as well as forward images. Utah state agency uses high-tech LiDAR scanning to maintain registers of the roadway assets and other maintenance inventories of the state highways. Similarly, the Illinois state agency uses the lasers to collect sensor data to determine rutting, roughness and faulting measures (Illinois Department of Transportation 2018). Data collected by the camera equipped vans and the lasers are analyzed and stored in the independent databases so that the future management work of the assets becomes trackable.

For the data collection process of the bridge, Human Insection is suggested for the detailed analysis of its structural components. Data collected is compiled and stored in the database.

Additionally, states like California and Utah are more resilient and considerate to focus on assets like drainage and Transporation Management Systems (TMS). These assets are inspected annually and later fed to the ever-growing database.

C. Performance measures

The performance measures being the deciding factor for the condition of the transportation assets, the FHWA provided the state agencies with a set of performance measures for pavement and bridge. These National Transportation Performance Measures are used by all the state agencies to determine the performance of the assets. Some state agencies do not only depend upon these measures, but they have developed some comprehensive performance indicators which are used to determine to performance of the assets.

For example, Tennessee DOT uses PQI (Pavement Quality Index) for pavement performance indication and Structural Deficiency for bridges. Similarly, the Illinois state agency uses CRS (Condition Rating Survey) as a pavement performance indicator and the California state agency uses PCI (Pavement Condition Index). A measure known as CCI (Critical Condition Index) is used by VDOT for pavement performance indication.

Therefore, the performance indicator for the transportation could be same or different according to the suitability of the indicators with the corresponding state agency. However, the indicators generally serve the same purpose.

D. Risk management

The risk management processes adopted by a few states are similar to each other as they have followed the standard procedure developed by the FHWA. North Carolina and Tennessee follow the guidelines provided by the FHWA. The risk management process is followed in an organized manner where the classification of the risks depends upon the responsible hierarchy for the risk. The methodology consists of the stepwise process of identifying, analyzing, evaluating and treating the risk. There is a provision by each state to respond to its anticipated type and severity of emergency events accordingly. For example, the state of California focuses on various emergency events like earthquake and climate change. One can see major subjects of focus have been developed by the CALTRANS to deal with specific risk categories such as project risk, seismic risk and climate change.

Probabilistic approaches are used by state agencies to go through the importance value of a particular risk. They are calculated in the form of matrix or scoring formulation. The severity of the risks is also classified according to the requirement of the state with respect to the geographical aspect.

E. Deterioration models

a. Hot Zone- Florida (12-4057)

TABLE 8: Margin of error for hot zone

Model	Margin of Error (Unit^2)
Mississippi Model	14.25
Louisiana Model	7.4
Indiana Model	3.285
Dubai Model	5.76

b. The comparison of the George 2000 Model with the measured IRI shows significant differences and margin of error of 14.25 Sq.Unit. The trend is followed at certain point but the change in the IRI expected by the model after the resurfacing (overlay in 2003) is tremendous. Also, the model is giving remarkably larger IRI values as compared to the MIRI. The other models seemed to follow the trend of the measured data very parallelly. But, again the models like 'Khatek et al.' and 'Gulen et al.' show slightly larger values. The Dubai model though considering only the age of the pavement as the contributing factor showed very close and better IRI values as compared to the all other models.Flood-Prone Zone (22-0124)

TABLE 9: Margin of error for flood prone zone

Model	Margin of Error ($Unit^2$)
Mississippi Model	32.50
Louisiana Model	22.13
Indiana Model	12.59
Dubai Model	8.28

All the four models in this case are following a constant trend as compared with the MIRI. But again, the IRI values from the Mississppi Model and Louisiana model provide results with slightly exaggerated values. On the other hand, the Dubai model again performs approximately close as compared to the other models. The Louisiana model which is developed by the Louisiana state agency though is following an acceptable trend, the exaggerated values are not near to acceptable.

c. Cold Zone- Minnesota (27-6251)

TABLE 10: Margin of error for cold zone

Model	Margin of Error ($Unit^2$)
Mississippi Model	50.77
Louisiana Model	29.75
Indiana Model	13.54
Dubai Model	4.58

The findings developed from the graph are a bit different as compared to the previous two case studies. In this case, neither of the four models is following a parallel trend with the measured IRI data. The measured data shows no change in the rate of the IRI after the reconstruction year. But the models are showing a substantial decrease in the IRI value in 2013. This shows that all the four models are missing some contributing and impactful factor which has not let the true IRI value of the pavement to go down despite of the overlay. Similar scenario can be observed here as far as the difference in the values is concerned. The Mississppi model showing significantly higher IRI data just similar to the previous case studies.

d. Moderate Zone – California (06-7456)

TABLE 11: Margin of error for moderate zone

Model	Margin of Error (Unit^2)
Mississippi Model	72.03
Louisiana Model	27.84
Indiana Model	10.41
Dubai Model	3.36

California case study showed the most disturbed trendline right from the beginning of the timeline. The Mississippi model once again performed unsatisfactorily, as we can observe an unparallel trendline with highly exaggerated IRI data. The start of the timeline i.e. the year 2000 shows higher measured IRI than the formulated IRI. This might be the effect of the consideration of the age of the pavement since last construction being zero. And the IRI measured by the LTPP was pre-repaired IRI value. So, this disturbance in the trendline is acceptable, but further the measured IRI shows very consistent straight line where each of the models fail as they naturally tend to consider the repair works of the pavement. This leads to a slight decrease in the formulated IRI value.

5.2 Limitations

This IRI prediction model analysis in the research is solely based on the data collected from the LTPP database. It helped to incorporate the technical characteristics of pavements like site specifications and historical weather data. But, the visual reconnaissance of the pavement sections is not done to consider the surrounding factors which may potentially affect the deterioration of the pavements. The pavement data from the year 2000 to 2017 is considered during the IRI analysis. It made the identification of pavement deterioration throughout this long span possible. That being said, it would be wrong to conclude that the pavements will behave in a similar pattern in the coming years. The variance of the future is not considered in this study.

The data for four case studies (pavement section) is used to perform the IRI prediction model analysis. This research does not incorporate multiple numbers of pavement sections in the form of case studies to include the average behavior of the pavements in the respective selected zones.

5.3 Conclusion

The TAMP report analysis clearly depicts the effectiveness of the pavement and bridge management systems developed by the different state agencies. The state agencies are robust and well organized as a result of the TAMP development. This report proves to be an effective guiding tool for the TMS as it contains all the required aspects of the process right from the past to the future of the transportation system of the respective state in a very organized manner.

It is evident that the freedom offered by the FHWA to the state agencies for the development of the TAMP reports along with the boundaries set by National Standards form a suitable approach for the state agencies to manage their transportation assets effectively. Each state agency is judged to have developed and implemented its TAMP with the consideration of various factors such as inventory, past conditions, budget, climate, and geography of that state. So, suggesting a common framework with mandatory processes to develop a state TAMP may prove to be unfair and ineffective. Some states like California, Utah and Virginia seem to be well ahead of others with respect to the way a complete Transportation Asset Management should be developed. They have independent individual portals and databases to record and analyze the collected data.

Implementation of advanced technologies has been done by the state agencies to make the data collection and analysis process easier and more accurate. Factors influencing risk management are identified and a well-thought approach developed by the FHWA for the state agencies appears to be suitable for current conditions and encourages effective use of the resources in the emergency events as well as predicting future unseen risks. This study helps in understanding the financial aspect of the system associated with the complete workflow of the TMS. The uniqueness of every state agency developed TAMP can be justified as they are corresponding well to their respective geographic and climatic conditions. For example, the California state being an earthquake-prone state focusses on the seismic resistant function of the bridge.

The state agencies around the U.S have developed various IRI models after extensive research and data collection which are being used by them for a long time. The comparison of LTPP measured IRI with the formulated IRI using four IRI models provided interesting results. Three out of the four models showed approximately parallel trend along with significantly higher values of IRI. The Dubai model despite using only ‘Age’ as an impacting factor proved to be much closer and accurate. Though this model was developed in Dubai with annual constant hot climate, it proved to be most accurate in predicting the LTPP performance data among the four selected models when applied to the selected pavement sections during the years included in the analysis. The other models which considered multiple deciding factors like TI (Temperature Index), AADT (Average Annual Daily Traffic), CESAL (Cumulative Estimated Single Axle Load), Age, Overlay Thickness and Modified Structural Number did not perform well in this research study given the parameters and approach utilized.

There are some other factors which are not considered (or effectively weighted) as each of the four models failed to accurately predict the change in the IRI values after the repair or reconstruction works of the pavements. This study should help state agencies develop a holistic approaches and a global model which would be able to consider key impacting factors leading the state agency to suitably predict the performance of the pavements in the coming future and plan accordingly.

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APPENDIX A: CRITERIA SHEET

TABLE 12. Criteria sheet

CRITERIA	TENNESSEE	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
YEAR								
TAMP report YYYY-MM	2018-04-27	2018-04-30	2018-00-00	2018-04-30	2018-04-04	2018-03-04	N/A	2018-01-01
VERSION	Draft	Draft	Interim	Final	Final	Final	N/A	Final
GOAL								
FEDERAL	To improve or preserve the condition of assets and the perfomance of the system	As per MAP-21 legislature design a risk based Trasnportation Asset Management Plan (TAMP) for all pavements and bridges on the NHS.	Similar to those set by MAP-21	The intent is to encourage states to achieve and sustain a state of good repair over the life cycle of transportation assets—regardless of ownership—and to improve or preserve the condition of the National Highway System (NHS).	N/A	N/A	N/A	N/A
STATE			N/A				N/A	N/A
ORGANIZATION	To create a poactive approaches for management of transportation assets with methodical processes that considers the strategic management of the overall transportation network	They have two main goal elements: 1. Safety and security for residents, visitors and bussinesses., 2. Agile, resilent and quality infrastructure.	1. Make the transportation network safer 2. Provide GREAT customer service 3. Deliver and maintain infrastructure effectively and efficiently 4. Improve the reliability and connectivity of the transportation system 5. Promote economic growth through better use of the infrastructure 6. Make the organization a great place to work	Sustain a Desired State of Good Repair over the Life Cycle of Assets. Achieve the Lowest Practical Life-Cycle Cost for Assets. Achieve National Goals. Achieve State Goals	1. Zero Fatalities, 2. Optimise Mobility, 3. Preserve Infrastructure	Develop a risk-based Transportation Asset Management Plan (TAMP) that describes how the State's roads and bridges on the NHS "will be managed to achieve system performance effectiveness and State DOT targets for asset condition, while managing the risks in a financially responsible manner, at a minimum practicable cost over the life cycle of its assets.	N/A	N/A

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
APPROACH							
PURPOSE STATEMENT	FDOT mission is to provide a safe transportation system that ensures the mobility of people and goods, enhances economic prosperity and preserves the quality of our environment and communities.	N/A	N/A	N/A	N/A	N/A	N/A
Approach	The Department produces a Program and Resource Plan (PRP), which consists of a complete 10 year projected budget for all major agency functions and programs. It is a summary document that contains the approved program alternatives and funding levels by fiscal years to accomplish program goals and objectives within expected revenue.	The NCDOT goal of delivering and maintaining our infrastructure effectively and efficiently is directly related to the MAP-21 national goal area for infrastructure condition in the performance of bridge condition on the NHS, and pavement condition on interstates and non-interstate NHS.	PennDOT as an organization is increasingly characterized by performance-based management. This aligns with using a data-driven asset management framework to identify and prioritize preservation, rehabilitation, and replacementprojects through the planning and programming process. In addition, having sound infrastructure condition data and effective processes for forecasting infrastructure condition to plan needed improvements provides a factual foundation for the PennDOT Connects initiative. The aim is to develop the most	N/A	N/A	N/A	N/A

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
PAST CONDITIONS							
1. PAVEMENT							
INTERSTATE	66	94.78	64.03	65	N/A	82.9	44.9
	33	4.62	34.4	35		6.6	52.1
	0.1	0.6	0.58	0		10.5	3.1
NON INTERSTATE	45	36.07	37.7	57.7	N/A	N/A	43.5
	55	62.73	60.08	36.3			54
	1	1.2	2.22	6			2.5
NHS ROUTES	50	N/A	45.3	N/A	N/A	N/A	30.4
	50		52.94				63.5
	1		1.77				6.1
NHS STATE ROUTES	N/A	N/A	N/A	N/A	N/A	72	
						12.7	
						15.3	
NHS LOCAL ROUTES	N/A	N/A	N/A	N/A	N/A	N/A	4.6
							82.9
							12.5
SHS	N/A	N/A	N/A	52.8	N/A	N/A	40.8
				38.6			53.5
				8.6			5.7
2. BRIDGE							
NHS	68.2	38.1	25.56	54.6	N/A	N/A	66.5
	30.6	55.2	68.91	45			28.7
	1.2	6.7	5.53	0.4			4.8
INTERSTATE	N/A	N/A	22.25	N/A	N/A	N/A	N/A
			73.01				
			4.74				
NHS STATE	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NHS LOCAL	N/A	N/A	N/A	N/A	N/A	N/A	N/A

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
NON -NHS	N/A	N/A	N/A	39.1	N/A	N/A	N/A
				59.7			
				1.2			
SHS	95.7	N/A	N/A	N/A	N/A	N/A	74.9
							21.8
							3.3
3. DRAINAGE	N/A	N/A	N/A	N/A	N/A	N/A	65
							23.5
							11.5
4. TMS	N/A	N/A	N/A	N/A	N/A	N/A	58.8
							N/A
							41.2
INVENTORY INFORMATION							
1.PAVEMENT							
NHS	9702	1338		5869	7140		
	42660	6357.3	23134			15769	56075
SHS	12107	74341.1					
	44181	143353				122711	49644
NON -NHS	6712				8749		
	25884		77448.6				
Overall				712045914			
2..BRIDGE							
NHS	5562	3563	5854		4807	N/A	10825
		49727932	87890.767		73235		234285883
NHS STATE ROUTES						N/A	
SHS	6926				3743	N/A	13160
					26553		245753328
Locally Owned	5633	20	6493			N/A	
		259471	16002.654				
Overall				19515339		N/A	
3. DRAINAGE	N/A	N/A	N/A			N/A	10647970
4.TMS	N/A	N/A	N/A	Lump	N/A	N/A	18837
	N/A	N/A	N/A	1223	N/A	N/A	N/A
	N/A	N/A	N/A	71820494	N/A	N/A	N/A
	N/A	N/A	N/A	7347574	N/A	N/A	N/A
	N/A	N/A	N/A	96160	N/A	N/A	N/A
	N/A	N/A	N/A	16553	N/A	N/A	N/A

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA	
PERFORMANCE MEASURES CONSIDERED								
1.PAVEMENT	<95	<95	<95	<95	N/A	<99	N/A	
	95-170	95-170	95-170	95-170		100-139		
	>170	>170	>170	>170		140-199		
	<5	<5	<5	<5		N/A	N/A	
	5–20	5–20	5–20	5–20				
	>20	>20	>20	>20				
	<0.20	<0.20	<0.20	<0.20		N/A	N/A	
	0.20-0.40	0.20-0.40	0.20-0.40	0.20-0.40				
	>0.40	>0.40	>0.40	>0.40				
	<0.10	<0.10	<0.10	<0.10		N/A	N/A	
	0.10-0.15	0.10-0.15	0.10-0.15	0.10-0.15				
	>0.15	>0.15	>0.15	>0.15				
	N/A	N/A	N/A	N/A		N/A	N/A	
	N/A	N/A	N/A	N/A	>5.5	N/A	N/A	
					>5.0			
					>5.0			
	N/A	N/A	N/A	N/A	N/A	N/A	MAX 100 (CURRENT: 43)	
	N/A	N/A	N/A	N/A	N/A		MAX 100 (CURRENT: 53)	
	N/A	N/A	N/A	N/A	N/A	N/A	MAX 100 (CURRENT: 88)	
					NBI			
2.BRIDGE	SUPERSTRUCTURE	DECK	≥7	N/A	>5	N/A	N/A	
	SUBSTRUCTURE	SUPERSTRUCTURE	5 or 6		>5			
	DECK	SUBSTRUCTURE	≤4		>5			
		CULVERT	≥7	N/A	>5	N/A	N/A	
			5 or 6					
			≤4					
	N/A	N/A	≥7	N/A	BHI	N/A	N/A	
			5 or 6		>90			
			≤4		80-89			
			≥7		70-79			
			5 or 6		60-69			
			≤4		<60			

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
3.DRAINAGE	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4. TMS	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Determination Criteria	N/A	N/A	A pavement segment is considered in good condition if all three of its distress components are rated as good, and in poor condition if two or more of its three distress componets are rated as poor	N/A	N/A	N/A	N/A
ASSET VALUATION							
1. Pavement	Total amount is given in the TAMP report which is the total of roadway and bridge that sums upto $65,044,752,479 while the turnpike asset values around $11,311,091,000	N/A	$ 6,70,00,00,000.00	₹ 24,00,00,00,000.00	$ 28,85,13,72,700.00	N/A	$ 98,96,39,00,336.00
2. Bridge	Total value of Roadway, bridge and turnpike: $ 76,35,58,43,479.00		$ 19,90,00,00,000.00	$ 5,00,00,00,000.00	$ 55,37,61,83,519.00	N/A	304826803801
3. Drainage	N/A	N/A	N/A	$ 5,82,50,00,000.00		N/A	N/A
4. TMS	N/A	N/A	N/A			N/A	N/A

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA		
TARGETS									
1. PAVEMENT									
NHS Detremined	N/A	N/A	No more than 5% of interstate pavements are rated as poor.	N/A	N/A	N/A		N/A	
SHS Determined		For currently good: PCI > 80%, For currently poor: PCI < 7.5%					CRACKING : 90	SPALLING: 90	POTHOLES: 90
Self Determined									
2. BRIDGE									
NHS Detremined	N/A	N/A	No more than 10% of NHS bridges are rated as poor.	N/A	N/A	N/A		N/A	
SHS Determined	N/A	Structural Deficiency < 2%, Condition Rating > 80%	N/A	N/A	N/A	N/A		N/A	
Self Determined									
3. DRAINAGE	N/A	N/A	N/A	N/A	N/A	N/A		N/A	
NHS Determined									
SHS Determined									
Self Determined									
4. TMS	N/A	N/A	N/A	N/A	N/A	N/A		N/A	
NHS Determined									
SHS Determined									
Self Determined									

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
LIFE CYCLE COST METHODOLOGY							
1. FOCUS OF PERFORMANCE	NETWORK LEVEL LCP	PROJECT LEVEL LCCA	NETWORK LEVEL LCP	NETWORK LEVEL LCP	PROJECT LEVEL LCCA	PROJECT LEVEL LCCA	NETWORK LEVEL LCP
2. REQUIREMENT							
FEDERAL	N/A	N/A	N/A	N/A	N/A	N/A	N/A
STATE	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3.METHODOLOGY	LIFE CYCLE PLANNING	LIFE CYCLE COST ANALYSIS	LIFE CYCLE PLANNING	LIFE CYCLE PLANNING			
Pavement	N/A	N/A	N/A	**Susutainibility Index** is used to define the life cycle plan for the particular pavement. Basically, Sustainibilty Index is the **ratio of work done to work required.**	N/A	100 percent automated data collection is done for all the pavements. Full assessment is done for the interstate, primary and secondary pavements after every 5 years.	LIFE CYCLE PLANNING
Bridge	N/A	N/A	N/A	After the determination of **NBI** ratings for bridge components, appropriate treatment is determined such as preservation, rehabilitation or replacement. Also, **BHI (Bridge Health Index)** is used to describe the overall condition of every bridge that is used as a structural performance measure and for prioritization	N/A	100 percent assessment of the bridges is done. Every bridge is inspected at leace once every 2 years in accordance with NBI.	LIFE CYCLE PLANNING
Drainage	N/A	N/A	N/A		N/A	N/A	LIFE CYCLE PLANNING
TMS	N/A	N/A	N/A	Prioritized treatment is given to the **ATMS** devices	N/A	N/A	LIFE CYCLE PLANNING

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
PERFORMANCE GAP ANALYSIS							
1. EXPECTED PERFORMANCE							
1. PAVEMENT							
INTERSTATE	N/A	N/A	21%	N/A	N/A	N/A	66
			78%				39
			100%				1
NHS ROUTES			14%				34.2
			79%				60.9
			7%				5
NHS STATE ROUTES							
NHS LOCAL ROUTES							
NON-NHS ROUTES							
SHS							60
							39
							1
2. BRIDGE							
INTERSTATE	Currently, 96% of SHS bridges are in good condition.	N/A	8%	N/A	N/A	N/A	N/A
			25%				
			7%				
NHS STATE ROUTE	N/A	N/A	9%	N/A	N/A	N/A	83.5
			61%				15
			18%				1.5
LOCAL NHS ROUTE	N/A	N/A	N/A	N/A	N/A	N/A	N/A

TABLE 12. Criteria sheet (continued)

			18%					1.5	
LOCAL NHS ROUTE	N/A	N/A	N/A	N/A	N/A	N/A		N/A	
FEDERAL NHS ROUTE	N/A	N/A	N/A	N/A	N/A	N/A		N/A	
SHS	N/A							83.5	
								15	
								1.5	
3. DRAINAGE	N/A	N/A	N/A	N/A	N/A	N/A		80	
								10	
								10	
4. TMS	N/A	N/A	N/A	N/A	N/A	N/A		90	
								N/A	
								10	
3. ASSET PERFORMANCE GAP ANALYSIS									
PAVEMENT	N/A	N/A	N/A	Pavements are currently and historically have exceeded targets for good and poor condition status.	N/A	N/A		N/A	
BRIDGE	N/A	N/A	N/A	Bridges are declining in aspect of quality consistently, so there is a need of a proactive approach	N/A	N/A		N/A	
DRAINAGE	N/A	N/A	N/A		N/A	N/A		N/A	
TMS	N/A	N/A	N/A	Current funding is well enough to replace the critical ATMS	N/A	N/A		N/A	

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTAH	ILLINOIS	VIRGINIA	CALIFORNIA	
DATA COLLECTION								
1. PROCEDURE	N/A	The Pavement Condition Survey (PCS) is conducted annually for all state maintained routes and non state maintained NHS routes using an automated data collection process. Both NHS and non-NHS routes are evaluated by the automated survey using high definition images for automated crack detection. Line scan sensors provide faulting and rutting measurements as well as International Roughness Indices (IRI).	Each year, the vendor collects data on 100 percent of NHS pavements and 50 percent of the non-NHS PennDOT-owned system, thus completing data collection on all non-NHS assets every two years. This schedule translates to approximately 28,500 segment-miles surveyed per year. Survey data is collected using transverse and single-point laser profilers, as well as high definition video images, and the system generates semi-automated condition ratings for pavement distresses.	UDOT maintains registers of many roadway assets through routine high-tech LiDAR scanning and maintenance inventories of the state highways. These registers are used to track the quantity and some condition information of each UDOT asset. UDOT also maintains an extensive database of current unit bid item costs compiled from the advertisement o new construction projects. This database is used to establish the replacement value of the quantified assets. Additional sources of information, such as R.S. Means, are referenced to establish a value for specialty items that are not in	The data is collected and processed by a vendor using an automated data collection vehicle (DCV). CRS surveys are performed in each travel direction on divided highways and in one direction on all other routes. . Downward-facing cameras are used to record pavement condition information and panoramic cameras provide visual references that are useful when viewing the images. . Lasers are used to collect sensor data to determine rutting, roughness, and faulting measures.	The data collection process is carried out using Continuous Digital Imaging and Automated Crack Detection technology. Camera equipped vans are used for capturing downward pavement images for crack detection as well as forward images. For the determination of roughness and rutting of the pavement advance sensors are used.	From 2015, Caltrans began annual pavement data collection through the Automated Pavement Condition Survey (APCS). It comprises of a Pavement Condition Survey Van which is mounted with advanced technology capable enough to collect data of the pavemnet types, profiles, smoothness, distress and images.	
	N/A	For bridges a combination of Initial, Routine, In-Depth, Damage, Special, and Fracture Critical Inspections are carried out by NCDOT inspection teams, as well as by private engineering	N/A	N/A	The agency conducts bridge inspections in accordance with the National Bridge Inspection Standards (NBIS)	N/A	The bridges in California are inspected through both Routine Inspection and Speciality Inspection. Both the inpsections are carried out by a registered inspector. During the Routine Inspection all the structural members of the deck, superstructure and substructure of the bridge are inspected.	

TABLE 12. Criteria sheet (continued)

CRITERIA	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA	
	N/A	N/A	N/A	N/A	N/A	N/A	Starting from 2005, Caltrans have been resilent enough to identify every drainage asset with an unique number. It is then evaltuated and inspected to feed the growing database which later helps to prioritise the asset for maintenance. The Culvert Inspection program plan reflects the completion of teh inventory of drainage assets by the year 2027.	
							A TMS Inventory Database is used to track all TMS assets. It helps the designer to fetch approximate replacment costs, compared to new costs. Best Cost Effective solution can be determined. Priorities for the required maintenance is are determined by evaluating the start date of the asset.	
2.FREQUENCY	N/A	TEMPORAL ANNUAL	TEMPORAL ANNUAL	TEMPORAL ANNUAL	TEMPORAL ANNUAL	TEMPORAL ANNUAL	TEMPORAL ANNUAL	
MAINTENANCE								
			The methodology framework for risk analysis by the PennDOT is given as, Risk = Likelihood x Consequence.	Pavement condition dashboard is developed, which is		The surface distress condition data have been used to identify recommended candidate pavement		

TABLE 12. Criteria sheet (continued)

CRITERIA	TENNESSEE	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
MAINTENANCE								
MAINTENANCE TYPE	N/A	N/A	N/A	The methodology framework for risk analysis by the PennDOT is given as, Risk = Likelihood x Consequence. PennDOT uses two key dimensions as there are more than one factor or attribute to a given risk. Those two key elements are: 1. Unknown	Pavement condition dashboard is developed, which is detailed and distinct enough to give a complete cureent idea of the asset condition. Regional level perform	N/A	The surface distress condition data have been used to identify recommended candidate pavement sections for preventative maintenance activities. These recommendations are based on decision trees developed for the needs analysis.	N/A
DETERIORITION MODEL								
1. PAVEMENT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Data collected from APCS is used in Caltrans's **Pavement Management System (PaveM)** which is a software used by Caltrans to model pavement deterioration and recognise the needfull pavement treatment priorities. PaveM uses various affecting factors like pavement condition, type, climate, traffic, and project history to propose the right repair treatment at the right time.
								The current network level life cycle model for bridges incorporates planned work generated by work recommendations and estimates

TABLE 12. Criteria sheet (continued)

CRITERIA	TENNESSEE	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
2. BRIDGE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	The current network level life cycle model for bridges incorporates planned work generated by work recommendations and estimates additional bridge needs based on the identification of defects during the inspection process. It depends on the percentage of the deck area whether in good, fair and poor condition. The model incoproates 0.45 annual detrioration rates from good to fair condition deciding the amount of minor mainteance work required. Also, 0.75 annnual deterioration rate is considered for the determination major repair or replacement work needed.
3. DRAINAGE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Network level LCP model is used for drainage assets.
4. TMS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	The 2017 SHSMP includes network level LCP for TMS assets which work on the factors like deteroration rates, treatments and unit costs.
RISK MANAGEMENT ANALYSIS								
1. REQUIREMENT					N/A	N/A	N/A	N/A
			Identification of risks that can affect condition of NHS pavements and					

TABLE 12. Criteria sheet (continued)

CRITERIA	TENNESSEE	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
4. TMS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	The 2017 SHSMP includes network level LCP for TMS assets which work on the factors like deteroration rates, treatments and unit costs.
RISK MANAGEMENT ANALYSIS								
1. REQUIREMENT					N/A	N/A	N/A	N/A
FEDERAL	Identification of risks that can affect condition of NHS pavements and bridges and the performance of the NHS, including risk associated with current and future environmental conditions.	Not defined in the report.	Identification of risks that can affect condition of NHS pavements and bridges and the performance of the NHS, including risks associated with current and future environmental conditions, such as extreme weather events, climate change, seismic activity, and risks related to recurring damage and costs as identified through the evaluation of facilities repeatedly damaged by emergency events carried out under part 667 of this title	A State DOT shall establish a process for the development of a financial plan that identifies annual costs over a minimum period of 10 years.				
STATE	Not defined in the report.	Not defined in the report.						
2. MANAGEMENT TYPE	PROJECT RISK MANAGEMENT	The risk management is identified as a continuous process whereby data is collected and evaluated with relation to established goals and objectives. Risks are identified as agency, program asset level.	PROJECT RISK MANAGEMENT	N/A	N/A	N/A	N/A	N/A

TABLE 12. Criteria sheet (continued)

CRITERIA	TENNESSEE	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
3. RISK ASSESSMENT	TDOT has selected a group of managers to serve on the risk management committee and perform a risk assessment and make recommendations to senior management on managing risk. In addition, many of the divisions consiider risk within their area of responsibility on an annual basis.	The department has a robust, long standuing plan thet has developed to the point that rosks which may lead to service interruptions have been mitigated or minimized.	NCDOT has selected a broad-based group of managers to serve on the risk management committee who represent each of the major business units within the department that contribute to the vision and guiding principles of the asset management plan for pavement and bridges. Additional members may be added to the committee, based on the needs of the department or to address additional areas of risk.	N/A	N/A	N/A	N/A	N/A
4. RISK MITIGATION PLAN	TDOT's risk management plan is not completed yet and is expected to be done by June, 2019.	At the agency and program levels, there is very minimal risk associated with funding shortages and cost increases which ultimately may result in service interruptions. The Department's primary source of funding for asset management activities comes from state-generated revenues. Funding allocations for pavements and bridges are taken directly "off the top" to ensure assets are maintained in a state of good repair.	1. Establishing context, 2. Identify risk, 3. Analyze risk, 4. Evaluate risk, 5. Treat risk.	N/A	N/A	N/A	N/A	N/A

TABLE 12. Criteria sheet (continued)

CRITERIA	TENNESSEE	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
FINANCIAL PLAN								
1. REQUIREMENTS								
FEDERAL	It should include cost estimates to implement the investment strategy.	N/A	N/A	N/A	N/A	N/A	N/A	Federal Regulations aquire that an annual level of investment to maintain asset condition for NHS pavements and bridges be included in the TAMP report. It is estimated that to miantain the current condition of the NHS assets aproximately $1.85 billion will be needed for 10 years.
STATE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	It requires that California develop a robust asset management plan which meets the federal TAMP requirements amnd alos includes on the SHS. The plan should cover all the four asset types.
2. FUNDING SOURCES								
FEDERAL	Planning and Research, Interstate system, Highway Construction, Transit, Air, Water and Rail, Aeronautics Econ Dev Fund.	Federal Aid	Federal Highway, transit and aviation administrations	N/A	N/A	N/A	N/A	Highway Trust Fund (HTF), Obligaton Authority, August Redistribution, Other Federal resources
STATE	Highway user tax, Miscellaneous Revenue, Fund Balances and Reserves, Bond Authorization, Aeronautics Econ Dev Fund, Transportation Equity Fund.	Fuel Sales Tax, State Comprehensive Enhanced Transportation System (SCETS) Tax.	Highway Fund, Highway Trust Fund.	N/A	N/A	N/A	N/A	N/A
OTHER		Transportation Financing Corporation, Local and other, Turnpike and Tolls, [illegible]	N/A	N/A	N/A	N/A	N/A	N/A

TABLE 12. Criteria sheet (continued)

CRITERIA	TENNESSEE	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA
2. FUNDING SOURCES								
FEDERAL	Planning and Research, Interstate system, Highway Construction, Transit, Air, Water and Rail, Aeronautics Econ Dev Fund.	Federal Aid	Federal Highway, transit and aviation administrations	N/A	N/A	N/A	N/A	Highway Trust Fund (HTF), Obligaton Authority, August Redistribution, Other Federal resources
STATE	Highway user tax, Miscellaneous Revenue, Fund Balances and Reserves, Bond Authorization, Aeronautics Econ Dev Fund, Transportation Equity Fund.	Fuel Sales Tax, State Comprehensive Enhanced Transportation System (SCETS) Tax.	Highway Fund, Highway Trust Fund.	N/A	N/A	N/A	N/A	N/A
OTHER		Transportation Financing Corporation, Local and other, Turnpike and Tolls, Right of Way Bonds and State Infrastructure Bank.	N/A	N/A	N/A	N/A	N/A	N/A
3. FUNDING AVAILABLE								
	$ 14,39,84,050.00	$ 12,86,27,00,000.00	$ 10,44,90,00,000.00	N/A	N/A	N/A	N/A	$ 35,75,50,00,000.00
	$ 1,03,76,10,100.00	$ 24,62,83,00,000.00	$ 41,75,75,00,000.00					$ 41,99,90,00,000.00
	$ 8,99,92,800.00	$ 11,44,80,00,000.00						$ 16,07,00,00,000.00
5. FUNDING ESTIMATED TO BE USED AFTER THE PRESCRIBED YEARS (BASELINE)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
PAVEMENT								$ 2,13,60,00,000.00
BRIDGE								$ 83,60,00,000.00
DRAINAGE								$ 10,80,00,000.00
TMS								$ 10,60,00,000.00
5. FUNDING ESTIMATED TO BE USED AFTER THE PRESCRIBED YEARS IN THE TARGET FUNDING SCENARIO								
PAVEMENT	$ 2,37,29,00,000.00	N/A	$ 7,87,60,00,000.00					$ 4,63,50,00,000.00
				N/A	N/A	N/A	N/A	
BRIDGE	$ 1,20,90,00,000.00		$ 4,90,48,00,000.00					$ 1,65,90,00,000.00
DRAINAGE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	$ 49,40,00,000.00

TABLE 12. Criteria sheet (continued)

CRITERIA		TENNESSEE	FLORIDA	NORTH CAROLINA	PENNSYLVANIA	UTTAH	ILLINOIS	VIRGINIA	CALIFORNIA		
DETAILED PERFORMANCE GAP ANALYSIS											
NHS ASSETS		N/A	N/A	N/A	N/A	N/A	N/A	N/A	GOOD	FAIR	POOR
INTERSTATE PAVEMENTS											
CURRENT PERFORMANCE									44.90%	52.10%	3.10%
10 YR EXPECTED PERFORMANCE									60.00%	39.00%	1.00%
10 YR TARGET PERFORMANCE									60.00%	39.00%	1.00%
CURRENT GAP									15.10%	13.10%	2.10%
10 YR PROJECTED GAP									0.00%	0.00%	0.00%
NON- INTERSTATE NHS PAVAMENTS											
CURRENT PERFORMANCE									25.50%	67.40%	7.10%
10 YR EXPECTED PERFORMANCE									34.00%	60.80%	5.20%
10 YR TARGET PERFORMANCE									34.10%	60.90%	5.00%
CURRENT GAP									8.70%	6.50%	2.20%
10 YR PROJECTED GAP									0.10%	0.00%	0.20%
NON-INTERSTATE NHS PAVEMENTS ON THE SHS											
CURRENT PERFORMANCE									43.50%	54.00%	2.50%
10 YR EXPECTED PERFORMANCE									57.60%	40.90%	1.50%
10 YR TARGET PERFORMANCE									57.60%	40.90%	1.50%
CURRENT GAP									14.40%	13.10%	1.00%
10 YR PROJECTED GAP									0.00%	0.00%	0.00%
NON -INTERSTATE NHS PAVEMENTS OFF THE SHS											
CURRENT PERFORMANCE									4.60%	82.90%	12.50%
10 YR EXPECTED PERFORMANCE									6.70%	83.80%	9.50%
10 YR TARGET PERFORMANCE									7.00%	84.00%	9.00%
CURRENT GAP									2.40%	0.00%	3.50%
10 YR PROJECTED GAP									30%	3%	1%
NHS BRIDGES											
CURRENT PERFORMANCE									67%	29%	5%
10 YR EXPECTED PERFORMANCE									80%	18%	2%
10 YR TARGET PERFORMANCE									84%	15%	2%
CURRENT GAP									17%	14%	3%
10 YR PROJECTED GAP									3%	3%	1%

APPENDIX B: IRI MODEL ANALYSIS SHEET

Column1	MIRI	PRECI	Age	ESAL	CESA	MSN	TOPTH	Fn	CF	Δ	TI	AADT	Mississppi Mod	Louisiana Mod	Dubai Mod	Indiana Model
2000	0.889	1191.9	13	450	2.477	5.15	0.0635	1	101242.53	3.41	720	1707.00	5.14	2.59	1.31	1.80
2002	1.074	1546.6	15	448	2.925	4.56	0.0635	1	150124.20	3.41	715	1753.00	5.68	2.68	1.41	1.86
2003	0.76	1482.8	0	447	0.447	9.17	0.0635	1	25687.94	3.26	690	1698.00	1.87	2.22	0.82	1.40
2004	0.851	1397.09	1	452	0.899	8.6	0.0635	1	51633.39	3.26	756	1818.00	2.95	2.28	0.85	1.43
2006	0.909	1320.9	3	325	1.64	7.34	0.0635	1	88924.39	3.26	789	2033.00	3.67	2.33	0.92	1.50
2009	1.113	1555.19	6	211	1.978	6.45	0.0635	1	149679.81	3.26	696	1338.00	4.21	2.38	1.02	1.58

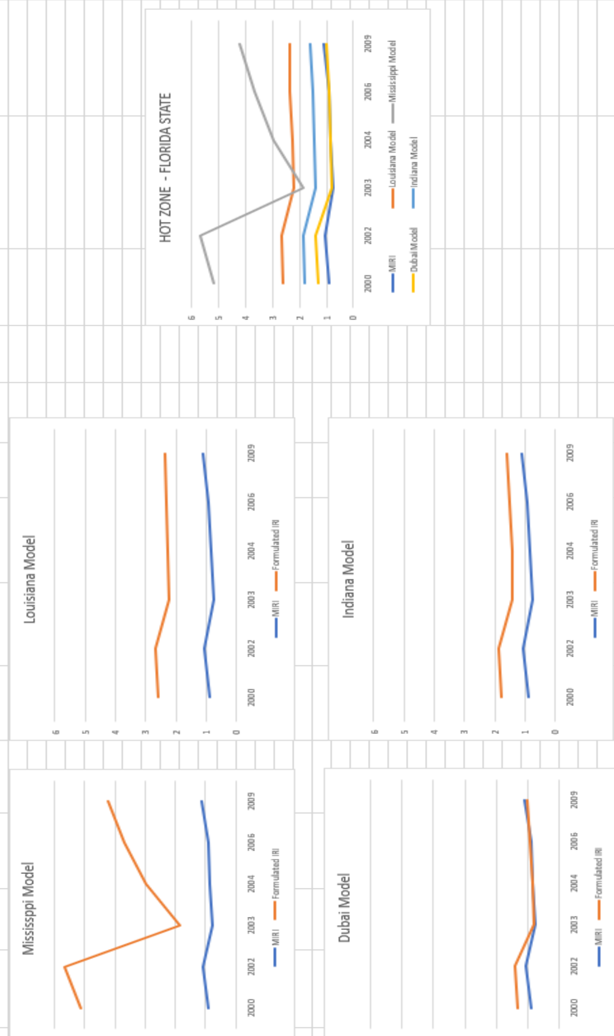


FIGURE 14: Hot zone

Column1	MIRI	PRECI	Age	ESAL	CESA	MSN	TOPTH	Fn	CF	Δ	TI	AADT	Mississppi Mod	Louisiana Mo	Dubai Mod	Indiana Model
2000	0.6712	786.4	2	0.091	0.178	6.8	0.0889	1	53349.32	3.28	1527.6	427.00	2.81	2.45	0.89	1.46
2003	0.7307	581.2	5	0.104	0.476	5.0	0.0889	1	79175.33	3.28	1636.7	473.00	3.52	2.54	0.99	1.55
2009	0.8108	621.5	11	0.128	1.184	4.5	0.0889	1	138236.5	3.28	1496.5	583.00	4.36	2.64	1.22	1.73
2011	0.903	630.9	13	0.137	1.454	4.0	0.0889	1	157542.4	3.28	1516.8	624.00	4.76	2.70	1.31	1.80
2013	0.9368	666.8	15	0.145	1.74	3.6	0.0889	1	175768.2	3.28	1453.6	669.00	5.19	2.74	1.41	1.86
2016	1.0462	690.6	0	0.158	0.158	8.2	0.0889	1	10704.3	3.20	1877.5	742.00	1.86	2.46	0.82	1.40
2017	1.0908	565.7	2	0.162	0.32	7.4	0.0889	1	18793.81	3.20	1946.4	769.00	2.81	2.50	0.89	1.46

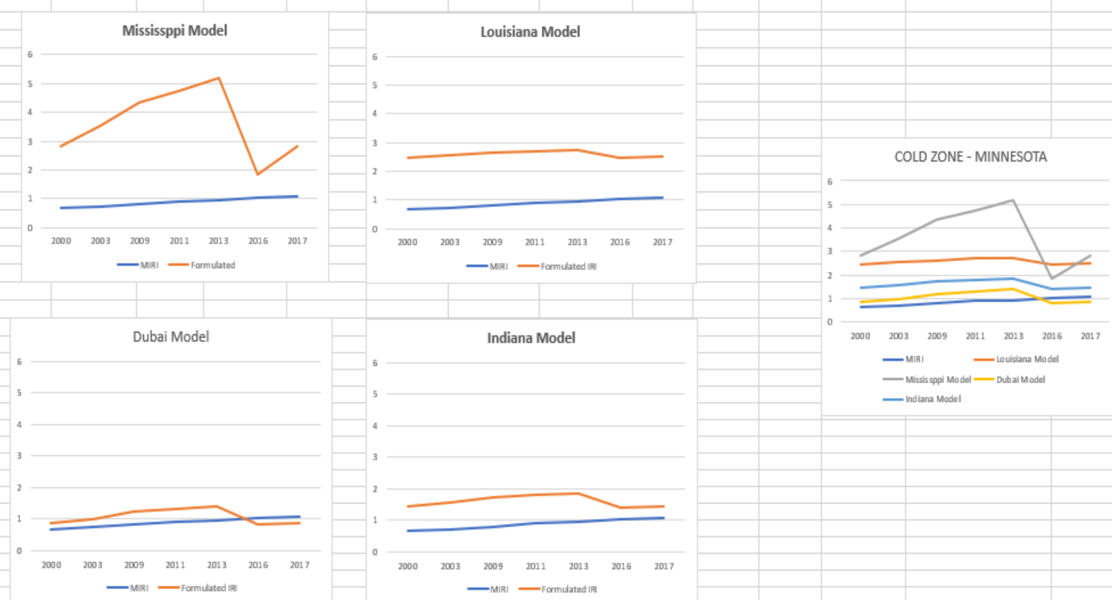
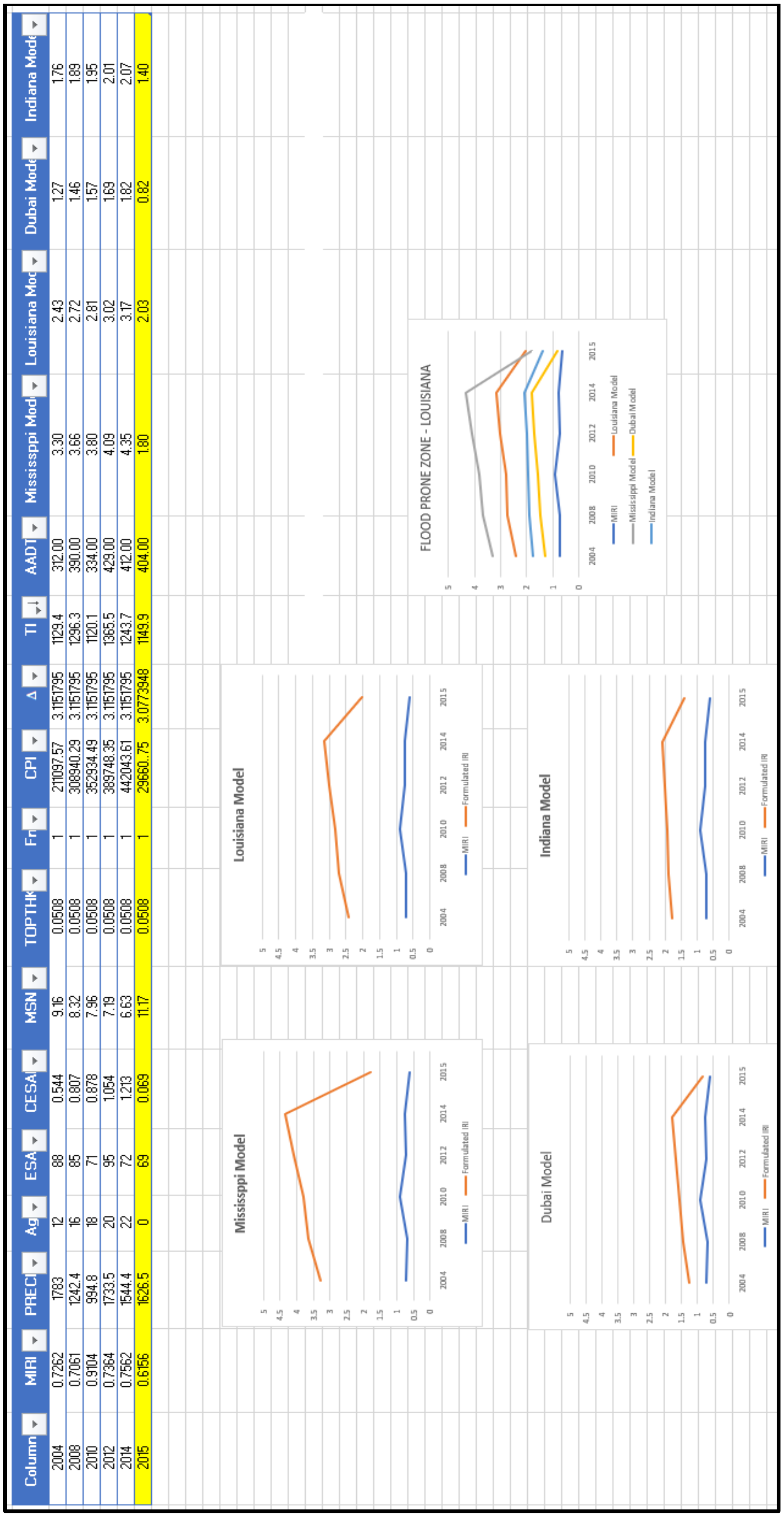
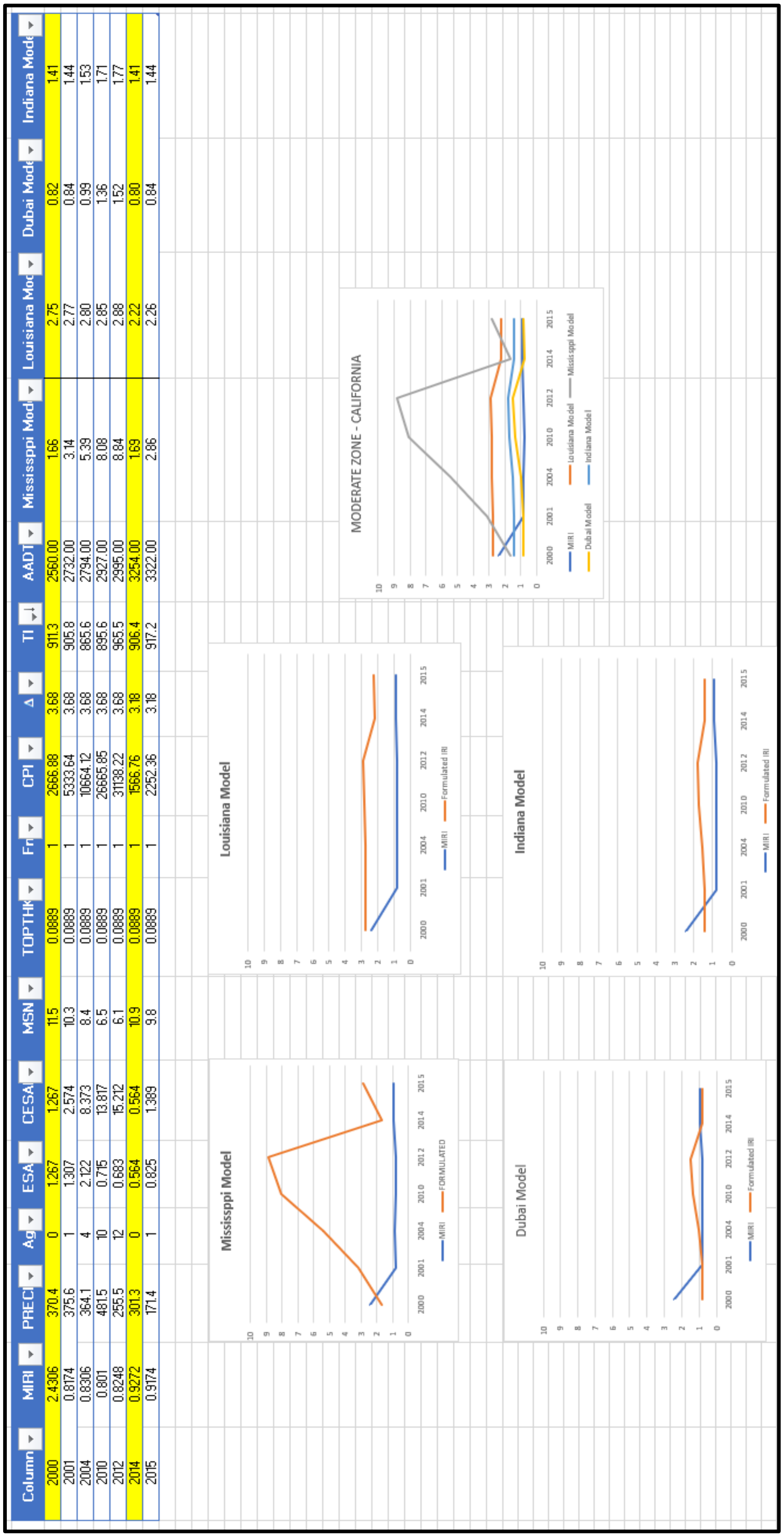


FIGURE 15: Cold zone



Column	MIRI	PRECI	Ag	ESA	CESAI	MSN	TOPTHK	Fr	CPI	Δ	TI	AADT	Mississppi Mod	Louisiana Mod	Dubai Mode	Indiana Mode
2004	0.7262	1783	12	88	0.544	9.16	0.0508	1	211097.57	3.1151795	1129.4	312.00	3.30	2.43	1.27	1.76
2008	0.7061	1242.4	16	85	0.807	8.32	0.0508	1	308940.29	3.1151795	1296.3	390.00	3.66	2.72	1.46	1.89
2010	0.9104	994.8	18	71	0.878	7.96	0.0508	1	352934.49	3.1151795	1120.1	334.00	3.80	2.81	1.57	1.95
2012	0.7364	1733.5	20	95	1.054	7.19	0.0508	1	389748.35	3.1151795	1365.5	429.00	4.09	3.02	1.69	2.01
2014	0.7562	1544.4	22	72	1.213	6.63	0.0508	1	442043.61	3.1151795	1243.7	412.00	4.35	3.17	1.82	2.07
2015	0.6156	1626.5	0	69	0.069	11.17	0.0508	1	29660..75	3.0773948	1149.9	404.00	1.80	2.03	0.82	1.40

FIGURE 16: Flood zone



Column	MIRI	PRECI	Ag	ESA	CESA	MSN	TOPTHK	Fr	CPI	Δ	TI	AADT	Mississppi Mod	Louisiana Moc	Dubai Mode	Indiana Mode
2000	2.4306	370.4	0	1.267	1.267	11.5	0.0889	1	2666.88	3.68	911.3	2560.00	1.66	2.75	0.82	1.41
2001	0.8174	375.6	1	1.307	2.574	10.3	0.0889	1	5333.64	3.68	905.8	2732.00	3.14	2.77	0.84	1.44
2004	0.8306	364.1	4	2.122	8.373	8.4	0.0889	1	10664.12	3.68	865.6	2794.00	5.39	2.80	0.99	1.53
2010	0.801	481.5	10	0.715	13.817	6.5	0.0889	1	26665.85	3.68	895.6	2927.00	8.08	2.85	1.36	1.71
2012	0.8248	255.5	12	0.683	15.212	6.1	0.0889	1	31138.22	3.68	965.5	2995.00	8.84	2.88	1.52	1.77
2014	0.9272	301.3	0	0.564	0.564	10.9	0.0889	1	1566.76	3.18	906.4	3254.00	1.69	2.22	0.80	1.41
2015	0.9174	171.4	1	0.825	1.389	9.8	0.0889	1	2252.36	3.18	917.2	3322.00	2.86	2.26	0.84	1.44

FIGURE 17: Moderate zone