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FINAL REPORT ~ FHWA-OK-19-07

ASSET VALUE PRACTICES AND FUNCTIONALITY

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January 2020

OKLAHOMA Transportation

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Providing a better understanding of the value of the State of Oklahoma's transportation assets as well as the maintenance activities necessary to keep them in a state of good repair is a key component of sustainable long-term asset management. This report enhances asset management planning efforts to better meet Federal requirements by providing a variety of approaches to valuation of transportation assets. The project also included a state of the practice review, a literature assessment, and a workshop and training overview of how to apply a variety of approaches. Losses to state highway functionality over time were categorized and examined to assess what actions can help preserve, reestablish, improve and enhance functionality in the future as a means to also evaluate the transportation network. The project identified ways to influence functionality of transportation assets, enhance safety and reduce future maintenance and investment expenditures. Ultimately, this effort detailed alternative approaches to business processes in Oklahoma with respect to asset management strategies and practices. Some further research is needed to determine if the new approaches would be worth the level of effort to launch new practices.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl	fluid ounces	29.57	milliliters	m
oz	gallons	3.785	liters	L
gal	cubic feet	0.028	cubic meters	L
ft^3	cubic yards	0.765	cubic	m^3
yd^3		meters NOTE: volumes greater than 1000 L shall be shown		m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit 5 (F-32)/9	Celsius or (F-32)/1.8		°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Table of Contents

List of Figures

List of Tables

INTRODUCTION

Effectively applying concepts of valuation and functionality allows agencies to effectively manage individual transportation assets effectively. To best maintain capacity and efficiency, functionality should be maintained and preserved in a proactive manner. This maintains safety, reduces unplanned maintenance activities, and protects the value of the infrastructure. Effective management requires functionality to be considered at every stage of an asset's lifecycle including planning, construction, maintenance and operations. Each of these areas affects how well an asset functions and within each area, causes of functional deterioration and associated countermeasures can be identified.

Providing a better understanding of the value of the State of Oklahoma's transportation assets as well as the maintenance activities necessary to keep them in a state of good repair is a key component of sustainable long-term asset management. This project's results provide a better understanding of the value of Oklahoma's transportation assets and the maintenance activities necessary to keep them in a state of good repair. The effort provides asset management planning enhancements, ultimately better meeting Federal requirements.

Losses to state highway functionality over time were categorized and examined including why functionality has been reduced in these areas and what actions can be taken to help preserve, reestablish, improve and enhance this functionality in the future. The project also identifies ways to influence functionality of transportation assets, enhance safety and reduce future maintenance and investment expenditures.

Types of Valuation Approaches

There are several approaches to valuation that can be applied to a transportation network. The following four characteristics form the core of valuation practices across the US.

- Cost - The cost of construction or replacement is a baseline metric for most of the valuation methods. In most approaches, this is the full value of a newly constructed, restored, or acquired asset before depreciation. In a popular valuation method, the asset value is simply equal to its replacement value. Cost is also perhaps the easiest data to obtain or estimate for most assets, though problems can arise when obsolescence is a factor, or when the assets exhibit a high degree of heterogeneity in terms of size, material, design, etc.

- Depreciation - Accounting depreciation of asset value occurs as the asset is consumed. In order to incorporate depreciation into asset valuation, we require assumptions about how depreciation occurs over time. Common methods of depreciation include linear depreciation, which assumes that the asset depreciates at a constant rate over time, and user cost, which assumes that the depreciation of the asset depends on the cost of upkeep (i.e. capitalization). Depreciation according to various curves other than straight line is sometimes used as well, such as sigmoidal or sinusoidal depreciation, which assume that the asset does not depreciate at the same rate over its lifetime. The type of assumption used has a great impact on how asset management is optimized and must be rooted in reality.

- Asset condition - Asset condition is used as an engineering alternative or a complement to accounting depreciation. Asset value is discounted based on current condition compared to optimal condition. Alternatively, discount of the asset value can also be determined by the cost of restoring to optimal condition. While the asset condition approach requires fewer assumptions than the depreciation approach, in order to optimize asset management, it also requires a reasonable picture of how asset condition changes over time with and without upkeep.

- Use value - Use value method measures the intangible benefits of the asset. This is the most sophisticated approach that has its foundation in recent advances in microeconomic theory and is still an active area of research using state-of-the-art methods in mathematics, statistics, and big data. Use value is perhaps the most compelling and useful in determining asset impact and risk and optimally allocating resources between high-use and low-use assets. However, this approach is also much costlier as it requires data that may not be readily available, as well as a very specialized skillset to produce and interpret the results.

In practice, combinations of each of the above may be evident in practices or preferred approaches. The OK TAMP uses a Depreciated Replacement Cost (DRC) methodology to identify the current valuation of highway and bridge assets. Depreciated Replacement Cost (DRC) represents the fair value of the asset. In this value determination, the Gross Replacement Cost (GRC) is reduced by the actual lost value due to asset consumption (AC), rather than in terms of reduced book value. In other words, the DRC approach calculates the consumption of the asset from its newly constructed state over time (age) and through wear and tear (condition). In principle, this provides the cost of replacing the assets to the level of service defined by the state.

Regardless of the approach, the valuation of the network ultimately becomes a question of whether or not the incoming investment is sufficient to maintain that valuation or increase the valuation. The practice is designed to serve as a management decision-making tool, one that can be readily communicated to the traveling public and stakeholders.

LITERATURE REVIEW

Transportation agencies, which are responsible for maintaining roads, bridges, tunnels and other critical infrastructure, require a structured and strategic approach to managing these assets over time. This management includes allocation of resources into maintenance and rehabilitation of these assets over their whole life. Within the transportation industry the concept of asset management is still relatively new; while overall goals including optimizing performance and cost-effectiveness of transportation facilities remain consistent, different agencies see the practice differently. Applying asset management principles often requires organizational changes in thought processes, planning, and decision-making efforts (FHWA, 2017a).

One over-arching goal of many asset management programs includes maintenance of a consistent level of service achieved at the lowest possible cost (FHWA, 2017a). While agencies may view asset management in a variety of ways, the Federal Highway Administration (FHWA) defines five core principles of asset management. First, asset management should be policy-driven; the decisions regarding resource allocation should be based on a well-defined set of policy goals and objectives. Second, it should be performance-based; the aforementioned goals must be performance measure based. Third, decisions on how to allocate funds to various means (preventative maintenance versus rehabilitation or pavement office versus bridges office) should be based on a thorough analysis of the tradeoffs of selecting one option over another. These decisions largely impact achievement of the policy goals and objectives set by the organization (FHWA, 2017a).

The fourth core principle suggests that decision-making is based on high quality information, which largely involves the use of current and credible data when analyzing different funding allocation options. Lastly, agency asset performance results should be closely monitored and this performance data should be used to provide both accountability of funding decisions and feedback on the decision-making processes (FHWA, 2017a). Using these fundamental ideas, a number of management systems (largely derived from the private sector) have been developed including management by objectives, goal-oriented management, risk-based management, and enterprise resource planning (FHWA, 2017a). The key difference between the aforementioned management systems and asset management is that asset management focuses on assets, asset condition, asset performance, and the resource necessary to maintain this performance to a predetermined level of service throughout the lifecycle of those assets.

Much of the transportation asset management work developed in the private sector, however the public sector must also adopt these mindsets, decision-making and strategies. Key challenges facing public agencies across the nation include maintaining infrastructure in a condition as good or better than is currently existing, developing and implementing a plan for infrastructure improvement, and working within budget constraints to plan, build, operate, maintain, and rehabilitate transportation facilities (FHWA, 2017a). With these goals in mind, comprehensive transportation asset management plans (TAMP) aid agencies in developing expected and desired projections of asset performance and infrastructure condition over time. These long-term asset strategies and financial plans are linked to sustaining infrastructure condition and level of service throughout its lifecycle (FHWA, 2016).

Using a TAMP is an inclusive method for addressing fund allocation across a set number of planning years that needs to be dedicated to rehabilitation and maintenance of assets. The financial component of this plan can be linked to various performance measures and infrastructure condition (FHWA 2016). Within this financial plan, asset valuation and deprecation are considered; asset valuation uses infrastructure conditions and creates monetary equivalents such as public wealth or equity. Depreciation describes the costs to public wealth and equity due to the aging and deterioration of infrastructure assets, which occurs due to use as well as neglect of required maintenance and rehabilitation (FHWA, 2016). Monetary valuation of transportation assets can be done using infrastructure age, type of infrastructure, infrastructure condition, or the components or costs associated with construction. Assets can also be valued based on their ability to generate income such as toll road service plazas, however, age, costs of construction or maintenance and condition are the most common means (FHWA, 2016).

The topic of functionality is integral to understanding asset management. Often times, performance measures are linked to infrastructure functionality, especially within the areas of planning land development, operations and capacity, right-of-way, safety, and infrastructure maintenance (Hard, Bochner, Li, Qi, Damnjanovic, & Frawley, 2009). These key areas can be linked with the success of transportation asset functionality. The group of lists below highlights various asset management components that can be linked to the functionality of those assets.

- Capacity/operational efficiency
    - Facility function (long distance, intercity, or local)
    - Signal optimization
    - Signal coordination
    - Operational assessments
    - Retrofits and enhancements
    - Minor enhancements (ramps, interchanges, turn lanes, geometrics, time managed capacity)
    - Network enhancements (parallel facilities, gap completion, bottleneck improvements, expansion)
- Right of way
    - Preservation/protection
    - Acquisition
    - Protection
    - Utility location and maintenance
- Safety
    - Road safety audits

  - Operational assessments
  - Sight distance review
  - Sign assessments and maintenance (traffic control, wayfinding)
  - Lighting assessments
  - Traffic control
- Infrastructure
  - Life cycle cost decision making
  - Sustainable materials, equipment, designs
  - Low maintenance infrastructure components
  - Maintenance (practices and scheduling)
  - Modern materials
  - Low maintenance equipment
  - Coordination on development planning/review
- Planning
  - Land use/transportation planning and decision making
  - Plan implementation (including prioritization)
  - Development review/coordination
  - Access/corridor management and preservation

Preserving functionality of transportation infrastructure aids in preserving the value of these assets. Additionally, preservation, maintenance and enhancement of transportation asset functionality help maintain capacity and efficiency, reduces congestion, improves safety, minimizes costs by reducing unplanned maintenance, and protects investment value (Hard et al., 2009). In conjunction with functionality analysis, the consideration of climate change influence must also be considered for sustainable long-term asset management. When considering functionality, agencies should also reprioritize assets subject to new sources of vulnerability brought on by climate change. This includes dramatic changes in storm frequency and severity, fluctuation in duration of seasons, and fluctuations from the past average temperatures throughout the year (Lambert, Wu, You, Clarens, & Smith, 2013).

Other changes affecting functionality include increases in travel demand. The growth in highway travel in the past 80 years has exceeded the growth of the public roadway network, resulting in increased congestion, increased travel time delays, and infrastructure deterioration (FHWA, 2017b). In the last 10 years, state transportation departments have been utilizing transportation asset management practices in an effort to manage their overworked infrastructure in a long-term and strategic manner. A key objective of transportation asset management (TAM) is to allocate limited resources to competing uses while attempting to maximize transportation system performance. System performance can be measured by mobility, reliability and safety (FHWA, 2017b). In an effort to analyze how state departments of transportation (DOTs) utilize TAM practices to address existing and anticipated future travel demand on their state infrastructure, the FWHA conducted a study using four state DOTs: California, Michigan, North Carolina, and Utah. For each state interviews were conducted and the following was documented: the extent and maturity of the state's TAM program, how the agency is using TAM to address travel demand issues within their state, and how the agency is addressing long-term investment needs (including long-term transportation planning, budgeting, and financial management) (FHWA, 2017b).

State Experiences with Functionality Use

Several states have adopted varying approaches to consider highway functionality as part of their asset management journeys.

Michigan

The state of Michigan maintains one of America's most mature asset management programs. Some components of the Michigan DOT (MDOT) include utilizing a statewide process, a honed focus on preservation of assets and functionality, goal, objective and performance measures and accurate and comprehensive data collection and distribution. Specifically, MDOT aims to maintain 95% of freeway and 85% of non-freeway state-owned pavements in "good" condition by 2008; they set the same goal for their bridges (FHWA, 2017b). The state's Asset Management Division manages and distributes highly accurate and complete data to potential customers including inventory of infrastructure, infrastructure conditions, current utilization, and forecasted future utilization. This data is also stored in the Transportation Management System (TMS) database, which includes an inventory of highway assets including bridges, pavement, intermodal systems, public transportation, and safety management systems. As a part of their TAM, MDOT utilizes Remaining Service Life (RSL) calculations to estimate the years remaining until major rehabilitation or total reconstruction will be required (due to cost-effectiveness) for transportation assets. Figure 1 shows a sample deterioration curve, which also includes three or more observed distress index measures.

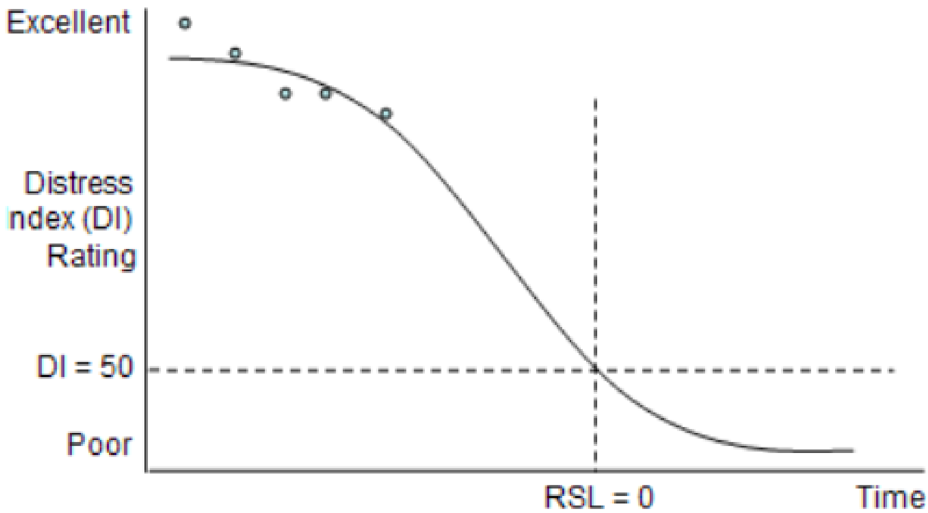

Figure 1: Sample RSL calculation curve (FHWA, 2017b).

This RSL analysis yields a percentage of assets within each of six categories created by Michigan DOT to separate pavements by their remaining service life as shown in Table 1 below. This allows the agency to prioritize funding allocation for maintenance and rehabilitation in a cost-effective manner.

Table 1: RSL categories (FHWA, 2017b).

Category	**RSL**	**Condition**
I	0-2 years	Poor
II	3-7 years	Good
III	8-12 years	Good
IV	13-17 years	Good
V	18-22 years	Good
VI	23-25 years	Good

From these findings, cost matrices, fix life values, inflation of strategy costs and strategies are identified. Alternative strategies may be required and are developed based on availability of resources. Additionally, Michigan's legislature has mandated that the state devote 90% of transportation related resources to the following: preservation, maintenance, safety and operations of its existing facilities.

Utah

In contrast, the state of Utah operates in a relatively decentralized manner where project recommendations are made via strategic TAM practices, which in turn form the 10-year Preservation Plan. Similar to Michigan, however, Utah focuses heavily on preservation of existing facilities (FHWA, 2017b). In fact, Utah DOT (UDOT) has implemented a number of initiatives to identify and manage roadway asset condition and performance. This allows for critical roadway assets to be managed and safety to be maintained (FHWA). Through TAM practices, UDOT has developed unique data-driven processes to systematically monitor and improve roadway asset condition and performance to meet expected state targets. As the nation's focus continues to shift from expansion to preservation of existing facilities, identification of transportation asset deficiencies must be identified for all 50 states. Within Utah specifically, roadway asset conditions were rated as above national averages as of the year 2010 and Utah's roadway assets had relatively low pavement deficiencies (FHWA).

UDOT, like many states, focused on functionality and worked to link infrastructure maintenance to performance and safety. For example, if the overarching safety goal is to reduce fatalities the agency may focus specifically on run-off-the-road crashes. In terms of roadway performance, pavement in key safety concern locations may be inadequately marked or graded; on the maintenance side, addressing these safety issues may include installing or enhancing existing rumble strips and making changes to existing shoulder grading (FHWA). Additionally, UDOT advertises its strategic goal as "Taking Care of What we Have" and operate under the philosophy that well maintained roads cost less over their lifecycle. To manage maintenance of the state's assets, Utah uses Maintenance Management Quality Assurance (MMQA) programs, which allow for evaluation of maintenance effectiveness and improvements to the maintenance process. These MMQA programs provide improved decision-making support by tracking asset condition thresholds that lead to required maintenance, data backing for maintenance fund allocation, tools for communication of maintenance needs to stakeholders and funding sources, and tools for measuring asset level of service (FHWA). A painstaking component for making this database successful is to obtain a 100% inventory of transportation and maintenance assets in the state. Additional improvements can be made to the condition reports of state assets by improving the accuracy of sample-based inventories, which is made challenging by the fact that many inspections are both subjective and time-consuming (FHWA). In lessons learned, UDOT cites flexibility in decision making as a key component of TAM success.

Colorado

In Colorado, lifecycle cost analysis (LCCA) has been widely used in asset management as a means for rational investment it the state's roadways for more than 25 years. The LCCA approach in use incorporates results from statistical research, pavement projects, and pavement types (FHWA, 2009). As of 2008, Colorado DOT (CDOT) maintained more than 8.7 million square yards of roadway surface and managed over 9,000 miles of state highways, over 3,400 state-owned bridges and 20 state-owned tunnels (FWHA, 2009). Challenges facing CDOT moving forward include high amounts of vehicle-miles travelled, population growth, harsh winter weather, extensive Interstate system repairs, and inadequate fuel taxes leading to a funding shortage (FHWA, 2009). Like many states, Colorado was facing severe budget limitations and was working to justify increased expenses associated with improvements and construction, often using LCCA. Many of the maintenance challenges in Colorado stem from the vast amount of roadways within the state, including a large number of Interstate miles, which are all continuing to age and now coming up on major maintenance and rehabilitation needs (FHWA, 2009). The use of LCCA is often reliability-based and includes parameters such as expected performance and expected costs accrued over the life cycle of the assets (Frangopol, 2011).

Some work is also being done to incorporate optimization into lifecycle cost analyses in order to expand the scope of conventional asset management systems to include raw material extraction and end-of-life stages of the infrastructure (Zhang, Keoleian, & Lepech, 2013). By considering these front and end stages of infrastructure lifecycle, the optimization methods for preservation of infrastructure aided in obtaining more accurate cost estimates, which gives agencies a more accurate valuation of their assets. The more accurate these valuations are, the better states are able to prioritize funding allocation when making maintenance-related decisions. A case study utilizing this optimization LCCA as compared to Michigan DOT's current preservation practices found that the optimal preservation strategy reduced costs by approximately 10% (Zhang, Keoleian, & Lepech, 2013).

California

In California's transportation department (Caltrans), there are no staff members dedicated entirely to asset management; however, the organization's leadership is working to establish transportation system performance measures for shaping infrastructure investments. Additionally, Caltrans was eager to participate in the FHWA study and was keen to learn more about asset management practices and ways the state could learn and benefit from the experiences of other state transportation agencies. Within their organization, Caltrans has TAM-related goals including safety, mobility, delivery of projects and services, flexibility of mobility choices, and preservation of California's resources and transportation investments (FHWA, 2017b). Caltrans also utilizes travel demand measurement and forecasting as a way to address future issues including roadway wear, capacity increase requirements, and safety.

North Carolina

North Carolina DOT (NCDOT) maintains over 75% of the state's roadway miles, which is a significantly larger share of state highway miles than many other states. Additional challenges include the rapid population growth in the state of North Carolina, which is among the fastest in the US (FHWA, 2017b). Due to this substantial growth, a key focus area of NCDOT's TAM program includes expansion. North Carolina has devoted considerable funds to system expansion to meet legislative requirements to complete construction of a pre-defined intrastate highway system (FHWA, 2017b). However, this focus on expansion is balanced by a second focus on preservation of existing facilities. Aiding in the TAM program work is extensive data, which was collected and is maintained by the NCDOT's TAM program. Available data includes NCDOT's asset inventory (pavements, bridges, and signals), pavement condition data, bridge condition data, and performance monitoring of traffic and ITS devices such as signals, signs, and pavement markings (FHWA, 2017b).

The heavy focus on expansion as well as the large proportion of roadway miles being maintained makes NCDOT a unique agency in respect to TAM program analysis. Since the state is required by legislation continue to expand its roadway assets, the state has funds programmable only for creating new capacity (FHWA, 2017b). Additionally, the prioritization of resource allocation is done via a scoring formula rather than explicit measures such as travel demand or economic analyses. NCDOT allocates 25% of funds equally to all divisions, 25% of funds based on how many intrastate miles still require completion, and the outstanding 50% of funds based on population with the state's divisions (of which there are 14). In support of this work, the state will begin using a decision support tool that focuses on benefit-cost analysis to aid in the programming of the capacity expansion projects (FHWA, 2017b). Overall, the FHWA study found that roadway wear, investment prioritization and benefit-cost and alternative project analysis were among the most commonly used travel demand TAM inputs. States used the TAM process to address travel demand related challenges including improving capacity, maintaining and enhancing functionality, and balancing preservation of existing facilities with increasing capacity as demand continues to grow (FHWA, 2017b).

Kansas

In the state of Kansas, asset management became a crucial focus upon the implementation of the GASB 34 reporting requirements. In response, the Kansas Department of Transportation (KDOT) has developed and utilized a TAMP for its assets including bridges, roadways, drainage structures and signs. Individual counties within the state, however, do not have sufficient funds or personnel for implementing and maintaining asset management systems like the one being used by KDOT (Friedrichs, 2007). Individual counties were surveyed and questioned on what TAM systems they are using, how maintenance is prioritized in their county and any software tools that are being used to support the TAM process. Questionnaire results showed Kansas counties with greater populations had interest in utilizing TAM systems and some had implemented such systems. On the other hand, smaller population counties often did not have sufficient resources or staff to implement any asset management systems within their county (Friedrichs, 2007).

Based on survey results, recommendations for employment of asset management systems were made to counties sorted by population range. That is to say, different recommendations for strategies and implementation were made to different sized counties. Counties were divided into three categories of population size: less than 5,000, between 5,000 and 50,000, and greater than 50,000 (Friedrichs, 2007). While a blanket application of TAM strategies is the most uniform way to achieve asset management objectives, the Kansas study found that at the county level, not all local agencies were equipped to operate asset management systems to the scale of the statewide effort at KDOT. Instead, at the county level a range of strategies can be suggested while keeping in mind county population and resources available; this allows for implementation of TAM processes to fit the availability of staff and resources as opposed to the county not utilizing any asset management practices at all.

Additionally, many Kansas counties were found to be lacking some or all of the key components of a comprehensive asset management system including asset inventory, methods for assessing asset condition and performance, determination methods for evaluating future system requirements, tools for selecting strategies, and methods for evaluating the effectiveness of aforementioned strategies. Roughly 25% of Kansas's counties stated in the questionnaires that they had implemented an asset management strategy or process in their county (Friedrichs, 2007). For counties with a population less than 5,000 it is critical to utilize the limited budget maintain and preserve current infrastructure; it is also not feasible to create a full-scale TAM system due to costs and staffing requirements. Instead, for counties or local governments of this size it is recommended to focus first on creating an inventory of county assets and maintaining this inventory in an up-to-date database as time passes. Inventory and asset information can be collected directly from work crews and can be used to aid in maintenance decisions (Friedrichs, 2007). Moving up in size to counties with 5,000 to 50,000 people, again asset inventory is a crucial first step in any size TAM process. Smaller counties may be able to utilize software meant for accounting purposes while larger counties may be able to invest in a complete asset management software system such as Cartegraph (Friedrichs, 2007).

In Kansas, only ten counties fell into the largest population category of more than 50,000 residents. Many of these larger counties have seen substantial growth in recent years (about 19% in 20 years), which in turn has brought higher traffic loads and faster deterioration of infrastructure such as roadways and bridges. The benefit of being a larger county is that many agencies have sufficient funds, resources, and staff to implement a larger scale TAM system in their county (Friedrichs, 2007). A complete inventory and condition database can be used for making maintenance related decisions; for smaller projects such as sign replacement or pavement patching or public complaints, decisions can be made using work order systems within the TAM software. For major maintenance projects such as roadway reconstruction or bridge replacement, the TAM software can aid in conjunction with agency officials input (Friedrichs, 2007). Addressing the adoption of TAM systems for different sized agencies based on size and available resources allows for a range of asset management strategies to be put in place without overtaxing the agencies resources.

West Virginia

A similar analysis was done in West Virginia, where many local governments are both small as well as rural (Stalebrink, 2008). While the GASB Statement No. 34 requirements may be more easily adoptable and complied with at the state level or in larger DOT agencies, smaller local governments may experience resource and staffing issues when meeting these requirements. Similarly, much of the guidance for implementation of these requirements has been focused on larger urban governments and state agencies. In West Virginia, however, many areas are small and highly rural. A total of 15 municipalities within the state were surveyed about their implementation of GASB 34, of which 10 responded (Stalebrink, 2008). A key difference between smaller rural agencies and larger government entities that was identified through this study is that the use of deprecation of assets for TAM processes was more highly used in small, rural and local governments (Stalebrink, 2008). Looking ahead to the state of Oklahoma, similar strategies may prove useful if county-level analysis of TAM systems and plans are completed.

Oklahoma State of the Practice

Like many other states discussed here, the state of Oklahoma is also facing challenges to meet the requirements of MAP-21 by creating their own TAMP (ODOT, 2018). The current TAMP covers the planning period of 2018 to 2027 and outlines a strategy for managing the state's pavements and bridges, as these are the state's most significant assets in terms of costs and extent. Within the TAMP, the agency set goals and objectives for managing these assets as well as documented the current conditions of infrastructure assets throughout the state. Tables 2 and 3 below show the inventory and conditions of Oklahoma's pavement and bridges rated as good, fair or poor.

Table 2: Inventory & conditions for OK pavements (ODOT, 2018).

Pavements	**Asset Inventory (lane miles)**	**Good**	**Fair**	**Poor**
ODOT Interstate	2,946	62.8%	36.3%	0.9%
OTA Interstate	1,039	74.4%	25.6%	0.0%
Total Interstate	3,985	65.8%	33.5%	0.7%
ODOT Non-Interstate NHS	6,684	43.6%	54.8%	1.6%
OTA Non-Interstate NHS	1,321	56.8%	41.5%	1.7%
Local NHS	127	N/A	N/A	N/A
Total Non-Interstate NHS	8,005	45.7%	52.7%	1.6%

Table 3: Inventory & conditions for OK bridges (ODOT, 2018).

Bridges	**Asset Inventory (square feet, 000s)**	**Good**	**Fair**	**Poor**
ODOT NHS	28,352	41.4%	53.9%	4.7%
ODOT Non-NHS	24,121	48.9%	43.7%	7.4%
OTA NHS	7,182	76.5%	23.5%	0.0%
Local NHS	748	17.4%	82.6%	0.0%
Total NHS	36,282	47.9%	48.5%	3.6%

As can be seen, the majority of Oklahoma's assets are in fair or good condition. Using this inventory and condition data, the state uses the TAMP to address lifecycle planning, financial planning to achieve these objectives, and risk management (ODOT, 2018). Throughout the state, Oklahoma DOT (ODOT) manages 30,373 lane miles of roads (9,630 are National Highway System or NHS miles) and 6,735 bridges (2,786 are NHS bridges). In terms of risk management, ODOT manages a variety of transportation risks including extreme weather uncertainty, regulatory changes, uncertain financial support for assets, and variability in travel behaviors. This risk management is a core part of the TAMP (ODOT, 2018). The TAMP also includes investment strategies, which are based on asset lifecycle planning; effective lifecycle planning includes a proactive means for maintaining or improving asset level of service by performing preventative rather than reactive maintenance. These efforts allow for better planning for fund allocation and often save costs just as individuals are recommended to continually perform oil changes on their personal vehicles every 3,000 to 5,000 miles traveled, which often aids in avoiding major maintenance costs down the line.

Another challenge faced in TAMP development is data fragmentation; when data on asset inventory or resource availability is incomplete or incorrect, decisions made based on this data are less than optimal (Halfawy, 2008). Coordination of data collection efforts and storage can aid in these efforts as well as having a well-established set of performance measures used for determining asset condition and performance goals (Halfawy, 2008). Similarly, this data quality improvement and standardization of current and objective asset performance will provide assistance during the development of asset management systems which can be shared across both intrastate and interstate agencies (Puffer, Freeman, & Jackson, 2008).

With accurate data on asset inventory and condition, ODOT is well positioned to analyze investment decisions. Considerations include funding source breakdown and objectives for asset management. Here, ODOT identified the following as objectives for their TAMP: maintain and improve bridge and roadway conditions, reduce asset performance related risks, improve data driven decision making, lower costs while still effectively delivering projects supporting TAM, increase and improve communication and transparency regarding project status and funding allocation, improve customer service with the public, improve safety, and improve mobility (ODOT, 2018). Within the TAMP ODOT identified six core funding sources including fuel tax, income tax, federal, National Highway Performance Program (NHPP), Surface Transportation Program (STP), and other state funds (ODOT, 2018). Minimum funding availability took a toll on the ODOT bridge system and in 2004 Oklahoma reached its highest number of structurally deficient bridges at 1,168. Following this ODOT made bridge condition a core concentration and was able to increase funds in order to eliminate state-maintained structurally deficient bridges. Since this work, ODOT has reduced the total number of structurally deficient bridges by nearly 75% (ODOT, 2018).

Having accurate and complete inventory and condition data for transportation assets such as bridges allows for better maintenance decision making as well as justification for increased spending or requests for increased funds. Maximizing this funding through risk-based and data driven decisions is a core part of the TAM program in Oklahoma. Similarly, data is useful for communication of state asset conditions, upcoming projects and funding allocation not only to stakeholders, but also to potential funding sources and the public (ODOT, 2018).

Reporting asset condition requires the use of standardized and well-established performance measures. For pavement condition ODOT utilizes the Pavement Quality Index (PQI), which is measured on a scale of 0 to 100 (higher numbers here indicate higher pavement quality). The score is a compounded measure of pavement distress including ride (discomfort experienced by road users traveling over the pavement measured using International Roughness Index (IRI), rutting (measuring depth of ruts along the wheel path), cracking (measured in terms of percentage of cracked pavement surface caused by excessive load, poor drainage, frost and temperature fluctuations, and construction errors), and faulting (occurs when adjacent slabs of pavement are misaligned vertically due to settlement, curling and warping). Summary condition indices are weighted and combined to form the final PQI (ODOT, 2018). For bridge performance measures, Oklahoma assesses and rates bridge's National Bridge Inventory (NBI) deck, superstructure, and substructure. Additionally, NBI classifies any culvert of 20 feet or longer as a bridge. These ratings are from 0 to 9 where the range of 7 to 9 is good, 5 to 6 is fair, and 0 to 4 is poor.

Since states are required to meet minimum performance objectives for the condition of infrastructure such as pavement, careful monitoring of asset conditions is key. For Interstate pavements, no more than 5% of lane miles can be in poor condition; if the requirement is not met, the state is required to reallocate funding in order to address the Interstate pavement conditions. Similarly, the total percentage of structurally deficient bridges cannot exceed 10% (weighted by deck area). To adequately satisfy these requirements and keep track of trends of asset conditions the TAMP includes a performance gap analysis between the current conditions and the state's targets (ODOT, 2018). The gap between the current scenario and the good repairs scenario are crucial for determining if asset performance will meet the required and desired goals and objectives. Gap analysis then allows the state to develop a long-term performance target; in the case of ODOT, the 10-year pavement target anticipates 59% of Interstate pavement conditions as good and only 4% as poor (ODOT, 2018). This analysis is done for all pavement and bridge types using current conditions and anticipated funding trends; end results for Interstate pavements are shown in Table 4.

Table 4: Pavement gap assessment (ODOT, 2018).

Interstate Pavements	**Good**	**Fair**	**Poor**
Desired State of Good Repair	65.3%	33.5%	1.3%

Interstate Pavements	Good	Fair	Poor
Current Performance	65.8%	33.5%	0.7%
Current Performance Gap	(-0.5%)	None	(-0.6%)
10-Year Projected Performance	59.7%	36.4%	3.9%
10-Year Projected Performance Gap	5.6%	None	2.6%

Similar analysis is done for any other assets included in the TAMP; for ODOT this includes bridges. Some states throughout the nation are utilizing public-private partnerships or P3 for delivering projects as a way to address infrastructure-funding gaps as this allows financial risks to be more evenly distributed (Garvin & Bosso, 2008). Following gap analysis, life cycle planning utilizes network-level adaptation, which aids in identifying costs for the asset from fruition to death. Here again, the principle that progressive investments in maintenance, preservation and rehabilitation throughout the asset life results in better conditions and lower overall costs (ODOT, 2018).

Once lifecycle planning for all assets is complete, risk management is considered using both formal and informal approaches. Formal processes are in place for managing project costs and schedules, using asset systems and conducting inspections. Oklahoma, like other states, is required to identify risks that could affect asset conditions, prioritize these risks, and create a plan for risk mitigation (ODOT, 2018). Figure 2 below outlines the FHWA recommended risk management processes and products.

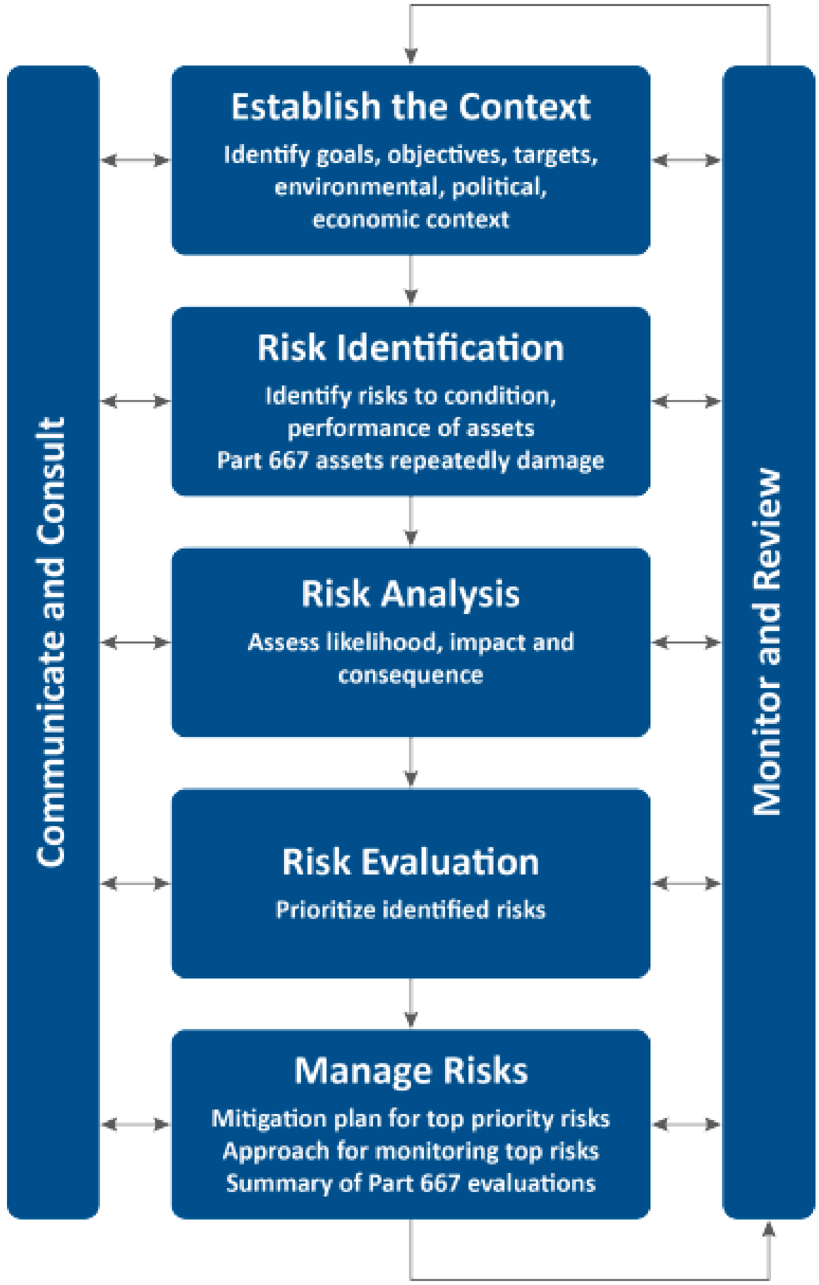

Figure 2: Risk management processes and outcomes (FHWA, n.d.).

Oklahoma DOT identifies seven risk categories that are addressed in their risk management portion of the TAMP. These include asset performance, highway safety, external threats (such as extreme weather, seismic events, terrorism, and accidents), finances, information and decision-making, business and operations, project & program management (ODOT, 2018). During this effort, ODOT conducted a risk management workshop where risk management concepts were reviewed a qualitative risk assessment matrix (an example of which is shown in Table 5) was introduced and utilized. The matrix allows the agency to identify risks and classify them based on likelihood of occurrence and the impact they would have if they were to occur. Each analysis has five categories that risks may fall into; when categories for both are obtained for a particular risk these align to one square of the matrix, which determines the risk score. Scoring risks using this method allows prioritization for addressing risks identified in the TAMP.

Table 5: Example of a risk matrix (ODOT, 2018).

Impact & Likelihood of Risk	**Likelihood: Rare**	**Likelihood: Unlikely**	**Likelihood: Likely**	**Likelihood: Very Likely**	**Likelihood: Almost Certain**
Impact: Catastrophic	Medium Risk	Medium Risk	High Risk	Very High Risk	Very High Risk
Impact: Major	Low Risk	Medium Risk	Medium Risk	High Risk	Very High Risk
Moderate	Low Risk	Medium Risk	Medium Risk	Medium Risk	High Risk
Minor	Low Risk	Low Risk	Low Risk	Medium Risk	Medium Risk
Insignificant	Low Risk	Low Risk	Low Risk	Low Risk	Medium Risk

The top priority risks as identified using the matrix methodology are included in the risk mitigation plan within the TAMP. For example, a top priority risk identified by ODOT is damage to bridges due to vehicle hits requiring diversion of previously allocated funds for repairs. The action identified in the mitigation plan includes industry education, different design considerations, and the pursuing of insurance reimbursements to cover costs (ODOT, 2018). Additionally, the risk mitigation plan outlines who will be responsible for what.

The TAMP also includes financial planning, investment strategies and areas for potential improvement. Within the financial plan, ODOT meets the federal requirement by including at least 10 years in the planning period, estimating costs of expected future work, estimating funding levels by fiscal year, identifying anticipated funding sources as well as estimating asset valuation and required investments to maintain this valuation (ODOT, 2018). Identifying costs, funding levels and funding sources allows for short and long-term funding allocation decisions to be made comprehensively and responsibly.

Utilization of proper investment strategies allows agencies to identify ways to improve financial decisions by directing funding resources to assets appropriately. Federal requirements stipulate that states establish defined processes for developing funding allocation strategies by performing gap analyses, performing lifecycle planning, performing risk management analysis and identify anticipated funding and future work costs (ODOT, 2018).

ASSET VALUATION METHODS

Assigning monetary value to transportation assets allows agencies to detail the value that is engrained within their numerous transportation assets and infrastructure. This also aids in the justification of allocating limited resources to maintenance and rehabilitation of these assets. For example, to the public, redoing a commonly used stretch of an urban arterial may seem like a waste of money and an inconvenience to travelers, especially if the road condition was not noticeably poorer than other local roads prior to construction. However, through the use of asset valuation, agencies can show how much value is already contained within the roadway and the projections of future value gained by rehabilitation of the roadway before the condition degrades further. The method of asset valuation is widely used in British transportation agencies to emphasize asset value as a substantial component of asset management strategies (FHWA, 2016). In fact, in Great Britain, the Chartered Institute of Public Finance and Accounting (CIPFA) worked in collaboration with the UK Roads Liaison Group (UKRLG) to develop a common “language” for assigning monetary value to physical transportation assets (FHWA, 2016).

Often, asset valuation concepts can be linked with performance measures via prediction models as well as lifecycle cost analyses. Research in Canada in recent years has focused on the integration of asset valuation into transportation asset management (Alyami & Tighe, 2016). Specifically, how asset valuation can be utilized to aid in financial decision-making as budgets grow increasingly limited and infrastructure continues to age and degrade. Degradation of infrastructure is a compounding issue; current transportation infrastructure all over the world is experiencing increased traffic loads, continued and increased use, and fewer resources allocated to preventative maintenance and rehabilitation. The incorporation of asset valuation into asset management systems is still a work in progress; Alyami and Tighe recommend an integration method in their 2016 research, which focuses on optimization of balancing costs and maintaining and enhancing the value of assets.

Determining the current asset value involves classifying the assets based on type, location or amount, assessing current infrastructure conditions and identifying current under-performing or deficient assets. Models can then be used to identify potential future deficiencies, future costs and return on investments and develop a future asset value prediction, which aids in decision-making (Alyami & Tighe, 2016). The application of these valuation methods is often classified by time frame: past, current, and future-based. Determination of asset valuation often includes the present value of assets based on historical costs adjusted for inflation and depreciation over time as well as incorporation of replacement costs. Data collected during the process of valuation may include initial construction costs, current construction costs, maintenance costs, performance condition of the assets, and age of the assets (Alyami & Tighe, 2018).

In the United States, standardization of asset management practices is being achieved through the implantation of the Government Accounting Standards Board's (GASB) Statement No. 34 requirements. These requirements established new financial reporting requirements for state and local governments across the US in order to make annual financial reports more comprehensive and usable. Included in annual reports is information about funds, operating results, and budgetary compliance. Statement No. 34 incorporates financial insights and performance from government managers. Financial managers are also better enabled to provide such analysis with the use of government-wide financial statements, which help agencies assess government finances, determine financial trends, evaluate revenue sufficiency, and make comparisons between governments. Identifying how other governments are utilizing funds and the success of these ventures. The new Statement No. 34 report structure can aid government officials in providing management-level analysis of funding decisions (Chait, 2008). Since the implementation of GASB 34, many research endeavors have aimed to determine whether these documentation requirements affect financial reporting (Garvin, 2008). Recent analysis of the usefulness of this additional information provided about infrastructure in the annual reports showed that the implementation of GASB Statement No. 34 did improve state highway infrastructure quality as well as indirect improvement in highway quality due to increased maintenance expenditures (Kim, Chen, & Ebdon, 2018).

To assess current asset valuation, ODOT uses the standard depreciation method put forth in the Government Accounting Standards Board Statement 34 (GASB 34). ODOT uses Depreciated Replacement Cost (DRC), which represents fair value of the assets and includes the Gross Replacement Cost (GRC) reduced by the actual lost value due to the asset consumption (AC) as opposed to the book value. The DRC approach considers consumption of the asset from the new state over time as it ages and as its condition deteriorates through wear and tear (ODOT, 2018). The DRC general equation is:

$$DRC = GRC - AC$$

In order to calculate the DRC of each pavement section, pavement current condition data and the ODOT developed deterioration models are used to assess an estimated age (EA) as well as remaining life (RL) of the pavement. RL is then compared to total expected life (EL) of the pavement section and a depreciation factor (DF) can then be calculated and used to establish the DRC, which also depends on a modeled reconstruction cost (RCC). The pavement calculations are shown below (ODOT, 2018).

$$RL = EL - EA$$

$$DF = \frac{RL}{EL}$$

$$RCC = Reconstruction\ Unit\ Cost * Section\ Lane\ Miles$$

$$DCR = DF * RCC$$

Calculated DCR values are then aggregated across the entire network in order to assess the total asset value of the pavements in the network (ODOT, 2018).

$$Total\ Asset\ Value = \sum_{i=0}^{n} DCR$$

ODOT models predict that the expected life of an asphalt pavement is around 38 years and the expected life of a concrete pavement is about 67 years. Using the above methods, the pavement asset valuation for all pavements is shown in Table 6 below.

Table 6: Pavement asset valuation (ODOT, 2018).

Description	Lane Miles	% Remaining	Replacement Value	Asset Value
All NHS	**12,134**	**73%**	**$8,561,026,196**	**$6,291,364,688**
ODOT Interstate	2,949	76%	$2,282,369,467	$1,741,288,409
ODOT Non-Interstate NHS	6,825	71%	$4,624,954,249	$3,287,837,098
ODOT Non-NHS	21,001	68%	$12,345,170,327	$8,346,014,718
OTA Interstate	1,039	81%	$737,685,678	$595,437,162
OTA Non-Interstate NHS	1,321	73%	$916,016,802	$666,802,019
All ODOT and OTA	**33,135**	**70%**	**$20,906,196,522**	**$14,637,379,405**

In summary, the depreciated cost method reduces gross replacement costs by actual lost value due to asset consumption. This method considers depreciation of the asset as well as asset condition and the remaining useful life of assets. However, data availability can present challenges as can the nature of the data. Expected life of various assets or even within one category, such as with pavements, may vary. Asphalt and concrete have different expected lives, which makes the calculations more complex.

Some alternative approaches were outlined. The following section provides a guide for applying these alternative approaches.

Guidance for Applying Asset Valuation Approaches

As part of the planning process, ODOT includes an estimate of project funding sources and investments in the TAMP; these estimates are used to achieve ODOT's desired conditions and performance in existing pavement assets. The financial plan includes a 10-year span and contains estimated costs of future work activities, estimated funding levels, anticipated funding sources, and estimated values of the existing pavement assets (ODOT, 2018). Funding sources are primarily toll revenues, income tax, and motor fuel taxes. The planned investments in NHS asset management is weighted toward pavement, with 67% of investments made to pavements and 33% to bridge assets (ODOT, 2018).

Cost

This section follows the Cost Approach for asset valuation. It is the most commonly used figure in a cursory review of the 52 submitted state DOT TAMP documents available through the FHWA website. ODOT has chosen to report remaining service life multiplied by replacement cost. The cost of construction or replacement is a baseline metric for most of the valuation methods. In most approaches, this is the full value of a newly constructed, restored, or acquired asset before depreciation.

Cost is also perhaps the easiest data to obtain or estimate for most assets, though problems can arise when obsolescence is a factor, or when the assets exhibit a high degree of heterogeneity in terms of size, material, design, etc. The cost of construction or replacement used as a baseline is common to most valuation methods. In most approaches, this involves using the full value of a newly constructed, restored, or acquired asset before any deprecation occurs. Here, the asset value is simply equal to its replacement value; this is the easiest approach in terms of data availability. For ODOT, Table 7 below shows the valuation of Oklahoma's pavements using the cost approach to valuation.

Table 7: Pavement asset valuation estimates using the cost approach

Description	Lane Miles	Replacement Value
All NHS	**12,134**	**$8,561,026,196**
ODOT Interstate	2,949	$2,282,369,467
ODOT Non-Interstate NHS	6,825	$4,624,954,249
ODOT Non-NHS	21,001	$12,345,170,327
OTA Interstate	1,039	$737,685,678
OTA Non-Interstate NHS	1,321	$916,016,802
All ODOT and OTA	**33,135**	**$20,906,196,522**

While this method is relatively simple to calculate, the cost approach oversimplifies valuation and may not provide meaningful decision quality information. It also does not take into account any differentiations based on land values, changes in material properties, or conditions. Many pricing aspects of reconstruction depend on external market forces and this approach does not consider asset condition; thus the results can be misleading.

In summary, the method sets asset value to the cost of construction or replacement. The cost approach method is easy to calculate and most data necessary for the work is readily available. Additionally, most practitioners find the cost approach relatively easy to understand. However, pricing may vary from estimates used in the approach due to external market forces.

Asset Condition

Asset condition is used as an engineering alternative or a complement to accounting depreciation. Asset value is discounted based on current condition compared to optimal condition. Alternatively, discount of the asset value can also be determined by the cost of restoring to optimal condition. While the asset condition approach requires fewer assumptions than the depreciation approach, in order to optimize asset management, it also requires a reasonable picture of how asset condition changes over time with and without upkeep. If the agency assesses asset conditions, then a valuation approach beyond replacement value or straight-line depreciation can be adopted for a greater breadth of analysis.

One use of asset condition data is in assessing by how much the asset is below the optimal condition level and using this to adjust the construction cost or replacement value. This requires asset current condition data and the percentage gradient that translates asset condition into depreciation (CDOT, 2016). Table 8 below shows the current asset conditions for Oklahoma pavement.

Table 8: Pavement condition (ODOT, 2018).

Pavements	**Asset Inventory**	**Good**	**Fair**	**Poor**
ODOT Interstate	2,946 (lane miles)	62.8%	36.3%	0.9%
OTA Interstate	1,039 (lane miles)	74.4%	25.6%	0.0%
Total Interstate	3,985 (lane miles)	65.8%	33.5%	0.7%
ODOT Non-Interstate NHS	6,684 (lane miles)	43.6%	54.8%	1.6%
OTA Non-Interstate NHS	1,321 (lane miles)	56.8%	41.5%	1.7%
Local NHS	127 (lane miles)	N/A	N/A	N/A

Pavements	Asset Inventory	Good	Fair	Poor
Total Non-Interstate NHS	8,005 (lane miles)	45.7%	52.7%	1.6%

Each pavement type has several condition indices as well as an over quality rating (PQI) that can be calculated using pavement distress data. Each index is calculated on a 0 – 100 scale based on associated distress information. These indices are then weighted and combined to calculate the PQI. For asphalt concrete pavements, indices such as ride, rut, and functional and structural data are obtained. The PQI weight of these items is shown in Table 9 below.

Table 9: PQI construct for asphalt concrete pavement (ODOT, 2018).

Pavement Type	Index	PQI Weight	Description
Asphalt Concrete Pavement	Ride	40%	Based on average IRI: 100 (IRI ≤ 60) or 0 (IRI ≥ 310)
Asphalt Concrete Pavement	Rut	20%	Based on average transverse rutting measured in inches: 100 (rutting ≤ 0.1”) 0 (rutting ≥ 0.66”)
Asphalt Concrete Pavement	Functional	20%	Based on transverse and miscellaneous cracking and raveling
Asphalt Concrete Pavement	Structural	20%	Based on fatigue cracking, patching, and potholes

A PQI range of 91 – 100 is considered Good, a range of 75 – 90 is considered Fair, and a range of 0 – 74 is considered Poor. A simple example of asset condition valuation would be to assess interstate pavements based on their PQI scores. If the asset value of a mile of OTA interstate pavements is $709,996.00 and the PQI rating of that mile of asphalt concrete pavement is 78, the asset condition value could be considered to be 78% of the optimal (100%) condition or 0.78*$709,996.00 = $553,797.00. This methodology could be applied to other pavement types and other assets such as bridges using asset condition ratings and optimal condition asset values.

The modified approach for GASB-34 reporting notes that infrastructure assets that are part of a network or subsystem of a network (eligible infrastructure assets) are not required to be depreciated as long as two requirements are met. First, the government manages the eligible infrastructure assets using an asset management system and second, the government documents that the eligible infrastructure assets are being preserved approximately at (or above) a condition level established and disclosed by the government. The condition assessments can vary over reporting periods. From a practical standpoint, infrastructure projects often overlap segments from previously capitalized projects. As a consequence, it is difficult to identify the actual segments or portions of costs related to improved assets. This begs an important question about how to properly account for the removal of historical costs.

In summary, asset value is reduced based on the current condition as compared to an optimal condition. This method allows for flexibility in choosing condition metrics for asset condition assessment, but practitioners should keep in mind that different measures will provide different valuations, which makes comparisons difficult. Despite this, asset condition governs the valuation assessment and the method is often easily understood.

Depreciation

To assess current asset valuation, ODOT uses the standard depreciation method under the Government Accounting Standards Board Statement 34 (GASB 34). While depreciation is relatively simple to calculate when data is available, the results of a deprecation method may be misleading especially for older assets with higher condition ratings. Changes in prices are also not taken into consideration. In straight-line depreciation, it is assumed that the asset loses a fixed value each year and this annual loss in value (depreciation rate) is calculated. Using a GASB 34 valuation example, Table 10 below, shows an example of straight-line depreciation for 1 lane mile of Oklahoma asphalt pavement constructed in the year 2001 (assuming a medium traffic volume between 2000 and 10,000 AADT).

Table 10: Pavement condition (ODOT, 2018).

Step	Factor/Calculation	Value
A	Year asset constructed	2001
B	Current replacement cost	$621,870
C	2001 Construction index (% of 2016 costs)	0.69
D	2016’s Estimate of 2001 construction costs (B x C)	$429,090
E	Annual depreciation cost based on 38-year life (D/38)	$11,292
F	15 years accumulated depreciation (E x 15)	$169,380
G	Recorded asset value in 2016 (D – F)	$259,710
H	Years remaining until asset value = $0 (G/E)	23 years

Essentially, if the replacement cost ODOT interstate pavements is estimated at $2,282,369,467.00 with a total of 2,949 lane miles (amounting to $773,947 per lane mile), each lane mile of asphalt pavements (expected life 38 years) depreciates by $20,367 per year while each lane mile of concrete pavements (expected life 67 years) depreciates by $11,551 per year. Again, this method, while simple, may provide results that are misleading as it does not account for maintenance and rehabilitation activity.
In summary, this method reduces asset value by a depreciation factor over time. It is a common method and many use straight-line depreciation, where the asset is assumed to depreciate by the same factor each year. The method is relatively simple to calculate and to understand. However, this method does not consider asset condition or usage of the asset. Additionally, changes in pricing may not be accounted for in the depreciation method.

Use Value

Use value method measures the intangible benefits of the asset and the application of these benefits to the infrastructure. In economic terms, this is the most sophisticated approach that has its foundation in recent advances in microeconomic theory and is still an active area of research using state-of-the-art methods in mathematics, statistics, and big data. Use value is perhaps the most compelling and useful in determining asset impact and risk and optimally allocating resources between high-use and low-use assets. However, this approach is also much costlier as it requires data that may not be readily available, as well as a very specialized skillset to produce and interpret the results. Average costs per driver in largest urban areas and statewide for vehicle operating costs, safety, and congestion are shown in Table 11 below.

Table 11: Average costs/driver of deficient roads (TRIP, 2017).

Urban Area	VOC	Safety	Congestion	Total
Oklahoma City	$832	$233	$1,110	$2,175
Tulsa	$859	$249	$984	$2,092
Oklahoma	**$1.9 Billion**	**$1 Billion**	**$2.1 Billion**	**$5 Billion**

Additionally, each year nearly $350 billion in goods are shipped to and from Oklahoma, mostly by freight truck (TRIP, 2017). From 2017, ODOT reports 66.9% of value being transported by truck, which amounts to $889.1 million. The five major inbound commodities include coal, agriculture, nonmetallic minerals, refined petroleum, and chemical products. The five major outbound commodities include fertilizer, agriculture, refined petroleum, food, and animal feed. When considering travel time indices, the Texas A&M Transportation Institute's Urban Mobility Report for 2019 provided the travel time index information for both Tulsa and Oklahoma City.

The travel time index (TTI) for Tulsa is 1.15 while the TTI for Oklahoma City is 1.19. An average TTI from those values is 1.17. In its purest sense, calculation of use value would require a minimum of the following data elements: time value of money, cost of delay and congestion, value of goods traveling on the network, cost of maintenance and repair, cost of original construction, and risk factors and valuation. A simplified approach could be done using the Oklahoma GDP to estimate a per person use cost on the system. The 2016 GDP in Oklahoma was $175 billion; the total population in Oklahoma in 2016 was reported as 3.93 million. This amounts to a GDP/person of $44,550. With 2,080 working hours per year, this amounts to a use cost on the system of just under $22 GDP/person/working hour.

Not many agencies utilize use value approaches due to the complex data needs associated with the method; however, this method would provide consideration to the economic impact or importance of the transportation assets. This allows a more holistic understanding of asset impact and risk factors for use in funding allocation decision-making. The value of the asset is considered to also include its use and the impacts a major breakdown or incident could have on the system.

In summary, the asset value is created considering intangible benefits of the asset and reflects realistic importance of the asset. This method is a holistic approach for budget decision-making as it considers the impacts of the assets and helps manage risks that may affect asset usage. However, the method is considered complex and requires various assumptions to be made and has high data needs.

Concluding Valuation Observations

Market-based approaches to valuation may be used where a pure market actually exists – for example the sale of rights-of-way or salvaged infrastructure components. Income approaches include the valuations of toll facilities or other PPP activities. Cost approaches are the most common, whereby the amount that would be required currently to replace the service capacity of the assets is considered. Table 12 below provides a summary of the valuation methods explored during this project and their various features, pros, and cons.

Table 12: Valuation methods comparison.

Method	**Features**	**Pros**	**Cons**
Depreciated Replacement Cost	GRC reduced by actual lost value due to asset consumption	Combines depreciation with an assessment of asset condition Considers remaining useful life of assets	Data availability Expected life varies for different assets and pavement types, making calculation more complex
Cost	Asset value is set to cost of construction or replacement	Easy to calculate Data readily available Easily understandable	Prices depend upon external market forces Method does not consider asset condition
Depreciation	Asset value is reduced by depreciation over time; common to use	Relatively simple to calculate Straight-line depreciation allows	Does not consider condition or usage of the asset Changes in pricing

Method	Features	Pros	Cons
	straight-line depreciation	for fewer calculations	not accounted for Results can be misleading especially for older assets with high condition ratings
Asset Condition	Asset value is reduced based on current condition compared to optimal condition	Asset condition governs valuation Easily understandable	Harder to calculate if historical costs are not present Different condition measures provide different valuation
Use Value	Asset value considers intangible benefits of the asset itself	Reflects realistic importance of asset Holistic basis for budget decisions	Requires various assumptions and many sources of complex data

WORKSHOP

On November 19, 2019, the research team coordinated a workshop from 1:00p – 4:00p at the Oklahoma DOT facility to explore and determine approaches to valuation that might be explored in greater detail. Mr. Jason Bittner facilitated the workshop using the following agenda:

Time	Topic	Notes / Outcomes
1:00-1:20	**Welcome & Introductions** **Announcements** **Purpose of Workshop / Agenda Review** *Jason Bittner, ARA*	
	EXHIBITS AND HANDOUTS *Agenda and Technical Memorandum*	
1:20-1:40	**Overview of Existing State Practices in Valuation** *RESULTS FROM STATE SURVEY AND INTERVIEWS* *Jason Bittner, ARA*	Understanding of Current State of the Practice
	EXHIBITS AND HANDOUTS *Powerpoint Slide Presentation*	
1:40-2:30	**Review of Valuation Approaches** *ANTICIPATED DISCUSSION* Possible applications in Oklahoma	Consideration of Variety of Approaches for Valuation to support decision making
	EXHIBITS AND HANDOUTS *PowerPoint Slides and Facilitated Conversation*	
Break		
2:45-3:20	**Overview of Functionality and Application to Pavements (Data Needs and Gaps)** *ANTICIPATED DISCUSSION* Strengths and Weaknesses of this Approach	Understanding Research into this field
	EXHIBITS AND HANDOUTS *Summary Exhibit from Technical Memorandum*	
3:20-3:45	***Application of Functionality Uses / Valuation Open Discussion***	Consideration of potential or desire to change current

	ANTICIPATED DECISIONS None	practices
	EXHIBITS AND HANDOUTS *Brainstorming / Open Discussion*	
3:45-4:00	***Open Dialog/Questions*** *ANTICIPATED DECISIONS* None	Gap identification and next steps
	EXHIBITS AND HANDOUTS *None*	

A slide deck was prepared and is available at the link below. Questions and access issues can contact Jason Bittner (jbittner@ara.com).
https://nextcloud.ara.com/nextcloud/index.php/s/iKorc2iSktHfHHR

The primary findings associated with the workshop included:

- There is a desire to use valuation in a manner that demonstrates a large value to decision makers, stakeholders, and the traveling public.
- There is a desire to use valuation to gauge the investment in the network from a monetary perspective.
- There is limited interest in pursuing a functionality-based assessment of the highway infrastructure at the current time.
- More information on the experiences in states including Colorado and Utah will be used to model the OK DOT approach to asset management.

Next steps that were identified at the workshop include a more thorough assessment of the existing state of the practice, including coordination between different asset classes evidenced in the Colorado DOT approach. A future research idea could be generated in this area or a peer exchange around the topic could be formulated by the project oversight committee.

In addition, the attendees of the workshop identified a need to use a standard approach to asset valuation since there are many different numbers being used in the agency currently. The Office of the Comptroller and the Office of Strategic Asset and Performance Management will need to collaborate on identifying a common valuation number to provide consistency.

Attendees of the workshop included:

- Theresa Stephens, Office of Research and Innovation
- Bryan Hurst, Office of Research and Innovation
- Matthew Swift, Office of Strategic Asset and Performance Management
- Matthew Mestre, Office of Strategic Asset and Performance Management
- Jeremy Planteen, Office of Strategic Asset and Performance Management
- Angela Sorels, Office of the Comptroller
- Jennifer Myers, Office of the Comptroller

LIFE CYCLE COST & FUNCTIONALITY ANALYSIS

Applying concepts of valuation and functionality across the network may not provide adequate information to help manage individual assets effectively. Instead, a cradle to grave analysis of a selected asset class (planning, construction, maintenance, or operations) was used to demonstrate the functionality parameters. Functionality is not a constant state, but rather evolves as the factors affecting functionality change over time. The asset category chosen for this analysis was interstate pavements; some interstate pavements are owned by Oklahoma Department of Transportation (ODOT) and some are owned by the Oklahoma Turnpike Authority (OTA).

Table 13 below shows the present condition of ODOT and OTA Interstate pavements; only 0.7% are classified as in Poor condition. Federal rules establish national pavement performance measures for state DOTs to assess pavement condition including percentage of pavements in the Interstate system in Good as well as Poor condition.

Table 13: Interstate pavement condition (ODOT, 2018).

Pavements	**Lane Miles**	**Good**	**Fair**	**Poor**
ODOT Interstate	2,946	62.8%	36.3%	0.9%
OTA Interstate	1,039	74.4%	25.6%	0.0%
Total Interstate	3,985	65.8%	33.5%	0.7%

Network-level condition assessments are calculated for each one-tenth mile pavement section by measuring pavement roughness, faulting, rutting and cracking. Measurements are aggregated and summarized as Good, Fair, or Poor. If a pavement segment has all metrics rated as good, the condition is labeled as “Good”. If two or more metrics are rated as poor, the pavement is labeled as “Poor” and any other combination of ratings is labeled as “Fair”. (ODOT, 2018).

Performance Measures & Life Cycle Planning

For interstate pavement, the Federal Highway Administration (FHWA) defines four pavement performance measures. Ride is an indicator of discomfort by road users determined using the International Roughness Index (IRI). Cracking is a measurement of the percentage of cracked pavement surface and is caused or accelerated by many factors including construction issues, operational issues, and environmental conditions. Rutting for asphalt is assessed by measuring the depth of ruts along the wheel path, usually a byproduct of heavy traffic and heavy vehicle access to the roadway. Faulting for concrete is indicated when adjacent pavement slabs are vertically misaligned in some way due to settling, curling and warping. ODOT measures Pavement Quality Index (PQI) on a scale from 0 to 100 where higher numbers indicate a higher quality and the score is made up of pavement distress data including ride, rutting and structure.

Table 14 shows various deteriorating mechanisms and their agents for pavements. Figure 3 shows a fishbone diagram of various agents involved in pavement cracking.

Table 14: Deteriorating mechanisms in pavements.

Deteriorating Mechanism	Agents	Examples
Excessive Loading	Traffic volume, traffic type	Cracking, rutting
Poor Drainage	Water	Cracking
Frost Heaves	Temperature changes, water	Cracking
Structural Deficiency	Construction flaws	Cracking
Vertical misalignment	Slab settlement	Faulting

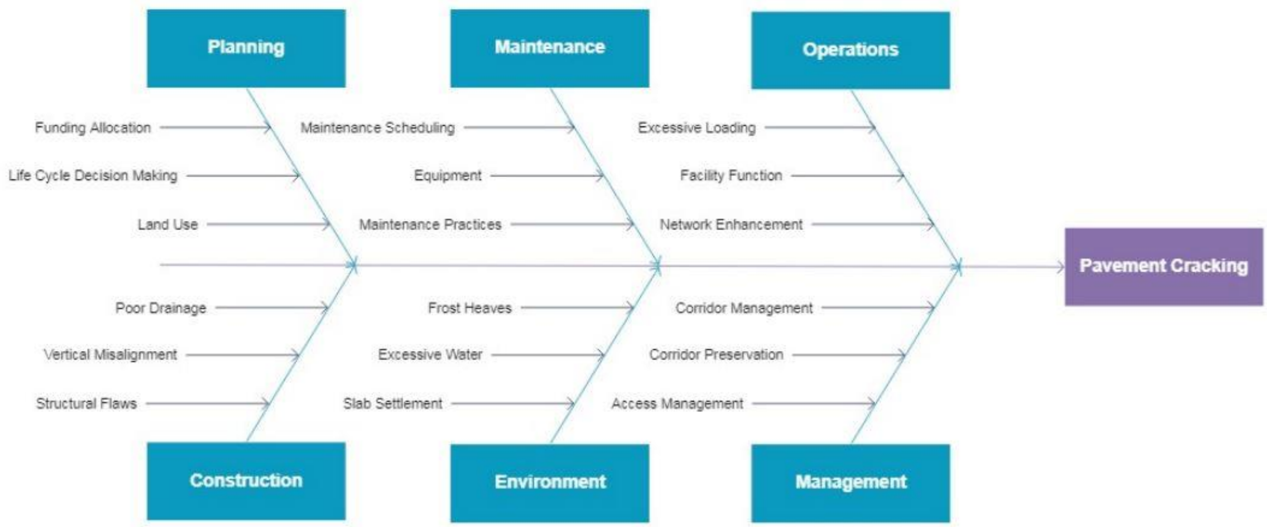

Figure 3: Pavement cracking fishbone diagram.

A multi-tiered functionality analysis allows for greater flexibility when it comes to funding allocation decisions and maintenance operation decision-making. For example, the agency may define what functionality means for a particular category of assets at the highest most ideal level, a mid-level, and a lowest acceptable level. Countermeasures for each level can then be identified and suggested. This flexibility means that if an asset category is not assigned enough funding to achieve the ideal level of functionality, a lower level can be accepted to meet funding constraints. For interstate pavements, this analysis has been created as pertains to Oklahoma DOT as shown in Tables 15, 16, 17, and 18 below. Each functionality level in the table shows the deterioration indicators for this level. This is done for the critical areas of planning, construction, maintenance, and operations specific to Oklahoma.

Table 15: Planning functionality indicators.

Planning Component	Highest Functionality	Mid- Functionality	Lowest Functionality
Land use	Very few conflicts with traffic movement, few utility relocations required	Some conflicts with traffic movement, some utility relocations required	Constant driveways, traffic conflicts, many utility relocations required
Life cycle cost decision making	Very few pavements in need of rehabilitation; preservation efforts sufficient	Majority of pavements in need of preservation or minor rehabilitation	Majority of pavements in need of major rehabilitation or reconstruction
Funding decision making	Funding allocated and available for required maintenance/year	Funding available for partial completion of required maintenance/year	Funding not allocated or available to complete required maintenance/year

Table 16: Construction functionality indicators.

Planning Component	Highest Functionality	Mid- Functionality	Lowest Functionality
Drainage	Cracking of: Asphalt <5% Jointed concrete <5% C.R. concrete <5%	Cracking of: Asphalt 5-20% Jointed concrete 5-15% C.R. concrete 5-10%	Cracking of: Asphalt >20% Jointed concrete > 15% C.R. concrete >10%
Vertical alignment of pavement	Faulting <0.10 inches Rutting <0.20 inches	Faulting 0.10-0.15 inches Rutting 0.20-0.40 inches	Faulting >0.15 inches Rutting >0.40 inches
Construction quality and material use	Pavement edge drops of <1.5 inches	Pavement edge drops of 1.5-3 inches	Pavement edge drops of >3 inches

Table 17: Maintenance functionality indicators.

Planning Component	Highest Functionality	Mid- Functionality	Lowest Functionality
Maintenance practices	Maintenance performed to recorded standards, standardized across region	Maintenance standards vary by office, variability in practices	No formal standards for maintenance projects
Maintenance	>75% of projects	50-75% of projects	<50% of projects

Planning Component	Highest Functionality	Mid- Functionality	Lowest Functionality
scheduling	completed on schedule	completed on schedule	completed on schedule
Access to maintenance equipment	All equipment needed is available; no overlap in equipment needs	Most equipment is available; some overlap in equipment needs	Most equipment is not available; excessive overlap in equipment needs

Table 18: Operations functionality indicators.

Planning Component	Highest Functionality	Mid- Functionality	Lowest Functionality
Facility function and LOS	Improvements bring facility function back to >50%; LOS >C	Improvements can only bring facility function back to <50%; LOS C-D	Can no longer improve functionality of existing facility to meet demands; LOS <D
Corridor management	None or rare frequency of incidents and rare occurrences of travel time disruptions	Moderate frequency of incidents and occasional travel time disruptions on the route	Near constant incidents and significant delays leading to unreliable travel times on the route
Access management and roadway loading	Cracking of: Asphalt <5% Joined concrete <5% C.R. concrete <5%	Cracking of: Asphalt 5-20% Jointed concrete 5-15% C.R. concrete 5-10%	Cracking of: Asphalt >20% Jointed concrete > 15% C.R. concrete >10%

Life Cycle Assessment

Life cycle assessment or cradle to grave analysis allows all inputs and outputs of a system to be examined over a period of time. Materials, emissions, energy, products, and processes required are summarized over the lifetime of what is being assessed. Life cycle analysis (LCA) can even be completed for items such as cola; Coca Cola performed such an analysis in 1969 in order to assess environmental impacts associated with the drink containers. For interstate pavements, the LCA begins with the raw materials and ends when those materials are disposed of or returned back to the environment in some way.

Raw materials include crushed base courses, pavement aggregate, binder, striping, and signage. The early stages of the LCA should also consider material transport and paving equipment; as the pavement life cycle continues, one must consider maintenance projects and rehabilitation. Outputs in the system include emissions from the material production process, material transport, equipment, and nay materials removed from the site and disposed of. Establishing boundaries is another important component of LCA; within the LCA of interstate pavements, analysis could include the production of the machinery used in an asphalt plant. Scope should be well defined, narrow enough to keep the analysis reasonable, but robust enough to consider vital elements. For interstate pavements, the LCA included initial construction as well as maintenance and rehabilitation efforts; if analysis is too brief, the full picture cannot be gleaned.

Table 19: Functionality indicators across project lifecycle (Hard, 2010).

Normal Cycle	**Functionality Indicator**	**Infrastructure Deterioriation Indicators**
New/improved facility	High level-of-service; no problems	None
Increased accessibility	More driveways	Driveway density
More development	Changes in land use	Driveway density or developed frontage on right-of-way
More traffic, safety concerns	More signals, driveways, turn conflicts, crash potential	Increasing maintenance
More development	Not applicable	Not applicable
Congestion, crash increase	More signals, driveways, turn conflicts, crash potential	Increaseing challenges to maintain traffic flow during maintenance if not planned
Continuing development	Not applicable	Not applicable
Need for improvement	Operational and/or safety breakdown	Higher level of improvement needed
Eventual right-of-way limitations	Conflicts between utilities in right-of-way	Utility relocations
Need for additional facility	Potential to improvement of functionality of existing facility	Can no longer improve functionality of existing facility to meet demands

Table 19 shows functionality indicators across the project lifecycle created from Hard's work on the subject. Functionality is not a constant, but rather constantly fluctuating throughout project lifecycle. The factors affecting functionality change over time, which causes the functionality itself to evolve. This cycle presents various indicators that can aid in identifying these changes as they occur (Hard, 2010). In Figure 4, the hypothetical highway project begins with a new or rehabilitated facility with no indicators of deterioration. However, as time progresses, more access points may be added and more development may change land use and add driveway density and frontage roads. As usage increases, traffic safety becomes a concern and maintenance practices increase to account for increased safety issues. When the need for improvement arises from operational and or safety issues, the facility may be improved with some conflicts or eventually replaced by or substituted with an additional facility (Hard, 2010).

During the LCA for interstate pavements, the inputs and outputs from Oklahoma were considered from cradle to grave including core life stages including planning, construction, operations, and maintenance and rehabilitation efforts. The lifecycle in its entirety for a project within Oklahoma DOT is shown in Figure 4 below and discussed individually by component in the following section.

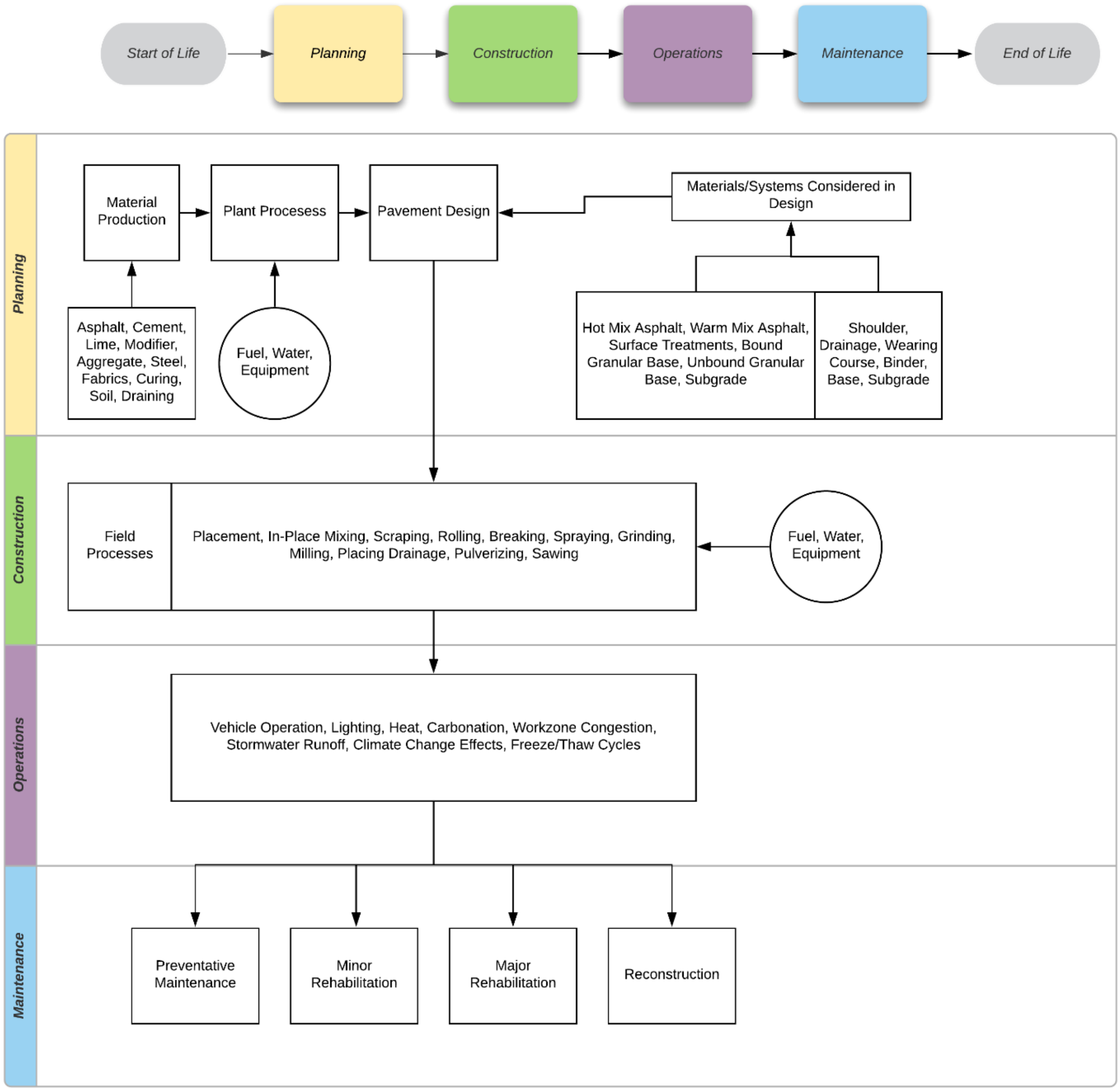

Figure 4: Interstate pavements lifecycle analysis.

Differences in pavement characteristics can cause various impacts on pavement use and lifecycle. For example, the pavement's structural responsiveness affects vehicle fuel consumption, emissions, noise, and ultimately, human health (FHWA, 2014b). Pavement roughness affects safety, noise, and vehicle characteristics such as fuel consumption and emissions; pavement permeability affects storm water runoff characteristics and temperature. All of these factors are considered in the pavement lifecycle analysis. Inputs to the cycle are also considered including energy use, resource use, emissions, toxicity, water use, and waste products (FHWA, 2014b). Key challenges in LCA include data collection, data quality, methodology for impact assessments, and weighting of impacts on decision-making processes (FHWA, 2014b). Using the pavement lifecycle processes shown in Figure 4, the functionality indicators for Oklahoma pavement lifecycle are shown in Table 20 below.

Table 20: Functionality indicators across interstate pavement lifecycle.

Normal Cycle	**Functionality Indicator**	**Infrastructure Deterioration Indicators**
New pavement construction	High level of service; no problems	None
Increased access and traffic loads	Heavy vehicles allowed; heavy traffic loads	Cracking, rutting
Preventative maintenance	Not applicable	Not applicable
Drainage issues	Excessive water pooling on pavement	Cracking
Freeze thaw cycles	Temperature changes and water pooling	Cracking
Vertical alignment changes	Slab settlement	Faulting
More safety and operational concerns	Potholes, cracking, faulting, rutting, and shoulder drop off	Increasing maintenance
Need for improvement	Operational breakdown and/or unsustainable maintenance needs	Higher level of improvement needed
Minor rehabilitation	Not applicable	Not applicable
Need for reconstruction	Potential to improve functionality of existing pavement	Can no longer improve functionality of existing pavements

Planning

Planning for project development is performed in a five-phase approach; in the first initiation phase, pertinent information about the project is gathered. Here, a project initiation meeting takes place to evaluate the project and identify available funds if the project idea matches the funding situation. In the second phase, of contracting, project solicitation takes place and the contract is developed. Preliminary project development including environmental studies, surveys, hydraulics, field reviews, right-of-way reviews, and utility reviews are conducted in phase 3. Finally, final project development takes place in phase four. Here geotechnical surveys are conducted, roadway and traffic plans are finalized, land is acquired, utilities relocated as needed, and the plans and specifications are prepared. Lastly, the project enters phase five, the letting phase (ODOT, 2019).

Construction

During construction, raw materials are acquired, processed, transported and manufactured. Inputs include the use of energy such as fuel, the use of resources, emissions, exposure to toxicity for workers and eco-toxicity such as water and soil contamination, water use, and the disposal of waste. Equipment must be mobilized and demobilized after construction activities are finalized. Additionally, any materials used for construction must be transported to the site and any excess must be transported away or disposed of (including reuse or recycle) (FHWA, 2014b).

Operations

Various pavement characteristics can impact operations; additionally, wear and tear over the lifecycle of the pavement can impact pavement condition and operations. Pavement roughness, macro-texture and structural response affect driver vehicle fuel usage, which impacts emissions. Surface texture of pavements as well as permeability affect noise generated from vehicle tire-pavement interaction. Additionally, surface texture and permeability affect surface friction of the pavement and hydroplaning, influencing safety of operations (FHWA, 2014b). Pavement permeability also affects storm water runoff characteristics; combined with drainage, issues with permeability and drainage can lead to deterioration including cracking. Other operational considerations are the effects of frost heaves and freeze thaw cycles; this affects water retention and temperature within the pavement and can lead to water pooling and cracking in the pavement. Slab settlement is also a concern and can lead to pavement misalignment and faulting.

Increased traffic and heavy vehicle traffic loads on pavement can lead to rutting and cracking and increase the need for maintenance. When the facility functionality is compromised as describe above, several issues can arise. Level of service on the facility may decrease to a point where improvements made cannot bring the level of service back to an acceptable level. Safety and maintenance issues can also lead to an increase in incidents, requiring high levels of incident management. If not properly managed, incidents on one route with deteriorating pavement can lead to congestion and eventual similar issues on other routes in a corridor. As maintenance needs increase, maintenance funds, equipment availability, and scheduling become a balancing act.

Maintenance

Maintenance is a core component of the pavement lifecycle; as operations take place various factors contribute to weathering of the pavement, requiring maintenance or rehabilitation. Factors contributing to deterioration are referred to as deteriorating mechanisms. Structural deficiencies such as alligator cracking, patch deterioration, aggregate issues, potholes, rutting, and depression may occur as a result of traffic loading over time. Water issues, which could result from flooding or drainage issues can lead to material deterioration such as raveling, weathering, and weather bleeding. Freeze thaw cycles can lead to swelling, cracking, and misalignments and temperature issues can also lead to shrinkage and creeping as well as longitudinal cracks. Issues with the pavement mix itself (bitumen or aggregate) can lead to depression, patch deterioration, and joint deterioration.

Maintenance activities can restore functionality in the pavement; ODOT recognizes several categories of maintenance and rehabilitation activities as shown in Figure 5 below.

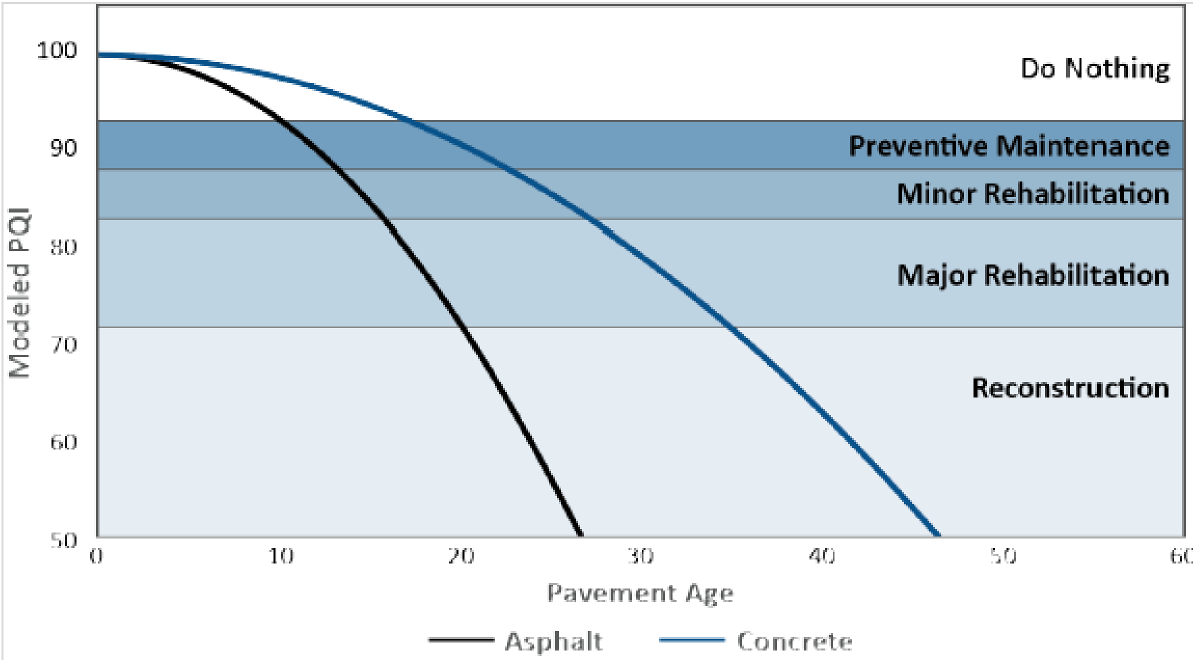

Figure 5: ODOT deterioration models and treatments (ODOT, 2018).

These various maintenance treatment categories result in different reductions in effective age and an extension in service life. Preservation activities including chip seal, bonded wearing courses, overlays, joint seal patching, all reduce effective ages by 5 years. Minor rehabilitation including cold mill overlays, joint seal patching and diamond grinds reduce effective age by 7 years. Major rehabilitation can reduce effective ages by 15 years and reconstruction can reset the effective age to 0. An example of various maintenance treatments to asphalt of differing ages and PQI's is shown in Table 21 below.

Table 21: Asphalt life cycle effects of maintenance categories.

Asphalt Age	**Modeled PQI**	**Countermeasure**	**Age Reduction (years)**	**New Effective Age**
10	95	Do Nothing	0	10
14	85	Preventive Maintenance	5	9
16	80	Minor Rehab.	7	9
20	70	Major Rehab.	15	5
27	50	Reconstruction	Resets to 0	0

Using the ODOT deterioration models and treatment categories as well as the asset condition categories, sample pavements can be evaluated as shown in Table 22 below. Here a pavement with the associated asset condition was evaluated using various functional performance measures and indicators of performance. For each condition, an appropriate treatment category was selected.

Table 22: Asset condition and functionality indicators.

Pavement Asset Condition	Functional Performance Measures	Indicators	Treatment Category
Good	Capacity	No road or lane closures due to pavement condition, no on-road work zones to correct pavement issues	None
Fair	Capacity	Few road or lane closures due to pavement condition, few on-road work zones to correct pavement issues	Preventative Maintenance Minor Rehabilitation
Poor	Capacity	Excessive road or lane closures due to pavement condition, multiple on-road work zones to correct pavement issues	Major Rehabilitation Reconstruction
Good	Operational Efficiency	Travel times and average speeds unaffected by pavement condition	None
Fair	Operational Efficiency	Travel times and averages speeds mildly affected by pavement condition	Preventative Maintenance Minor Rehabilitation
Poor	Operational Efficiency	Travel times and average speeds highly affected by pavement condition, average trip length increased due to pavement issues	Major Rehabilitation Reconstruction
Good	Safety	No roadway	None

Pavement Asset Condition	Functional Performance Measures	Indicators	Treatment Category
		segments not meeting safety standards, no vehicle collisions attributable to pavement condition	
Fair	Safety	Few roadway segments not meeting safety standards, few vehicle collisions attributable to pavement condition	Preventative Maintenance Minor Rehabilitation
Poor	Safety	Multiple roadway segments not meeting safety standards, high incidence of vehicle collisions attributable to pavement condition	Major Rehabilitation Reconstruction

Treatment Selection

Treatment selection for preventative maintenance and minor rehabilitation need are based on the PQI approach. Decision trees are used to support project decision-making and treatment selection. After completion of associated maintenance treatments, various improvements can be gleaned including increased capacity, increased strength, and reduction in aging and restoring serviceability. Table 23 shown below indicates the maintenance activity (from ODOT's four identified categories), the PQI range for interstate pavements associated with the maintenance activity, and the potential benefits. Pavements in a specified PQI range may be improved in a range of ways using various maintenance practices. For example, a segment of interstate pavement with a PQI value of 45 would gain serviceability and a reduction in aging by performing any maintenance activity; however, to gain in all four areas (capacity, strength, aging, and serviceability) reconstruction is the only acceptable option. However, if funding does not allow for this, then a lower maintenance activity could be chosen for the tradeoff of gaining in two of the four areas (such as serviceability restoration and aging reduction).

Table 23: Maintenance treatment categories.

Type of Activity	**PQI Range**	**Purpose: Increase capacity**	**Purpose: Increase strength**	**Purpose: Reduce aging**	**Purpose: Restore serviceability**
Reconstruction	0 < PQI ≤ 72	Yes	Yes	Yes	Yes
Major Rehabilitation	72 < PQI ≤ 83		Yes	Yes	Yes
Minor Rehabilitation	83 < PQI ≤ 88			Yes	Yes
Preservation	88 < PQI ≤ 93			Yes	Yes

Factors affecting PQI for asphalt concrete pavement include ride, rut, and functional and structural factors. For jointed concrete pavement PQI considers ride, fault, joint, and slab cracking and breaking. Lastly, for continuously reinforced concrete pavements, PQI includes ride and structural factors.

CONCLUSIONS

Asset valuation is the process of estimating the current monetary value of an agency's assets. Proper valuation supports robust investment decisions and trade-off analyses, improves asset management, leads to better evaluation of risk and resilience, informs economic analysis of highway system/investment, shows good stewardship of public assets, and justifies additional investment in assets of varying infrastructure types. A number of options are available to states for providing valuation. Although GASB34 requires the use of historical costs for valuation of assets in the CAFRs, there is no prohibition on using other valuation estimates for planning, communication, or asset management purposes. The key part is agreeing upon some "book value" – or a generally accepted number that is easily understood, validated, and used as a baseline. British and Australian accounting guidelines call for agencies to report the "fair value" of assets, not historic costs. These guidelines also allow the conditions of assets to influence their book values. Market-based approaches to valuation may be used where a pure market actually exists – for example the sale of rights-of-way or salvaged infrastructure components. Income approaches include the valuations of toll facilities or other PPP activities. Cost approaches are the most common, whereby the amount that would be required currently to replace the service capacity of the assets is considered. It is essential to remember that asset valuation complements typical asset performance measures and processes, it does not replace them. The ability and willingness to track value does not replace a well-designed TAMP or maintenance process. Since ODOT assesses asset conditions, it can adopt a valuation approach beyond the current replacement value or straight-line depreciation similar to recommendations being implemented in Colorado. Costs for procuring additional data should be minimal. Some potential asset valuation approaches may include:

- Condition-based depreciation whereby an asset value starts at construction cost or replacement value and is discounted by percentage based on range from the optimal condition. This approach requires asset condition data as well as a percentage gradient that translates asset condition into depreciation.

- Repair cost approach where construction cost or replacement value is discounted by how much it takes to restore the asset to optimal condition. This approach also requires asset condition data as well as estimated repair costs.

- For where asset condition data is not available, a straight-line depreciation approach can be employed based on expected service life.

In Oklahoma, current management strategies are founded on demonstrating a consistent value for the transportation network. Several different values are regularly reported, depending on the context and intent. The research findings, coupled with the workshop results, demonstrate that using a combination of use values and accounting for developmental land value costs is critical for providing a value that all parties can begin reporting consistently. This approach would differ from the DRC values presently used in the TAMP.

REFERENCES

Alyami, Z., & Tighe, S. L. (2016). *A methodology for integrating asset valuation in transportation asset management.* Paper presented at the Proceedings, Annual Conference - Canadian Society for Civil Engineering.

Alyami, Zaid; Tighe, Susan L. Asset Value Index for Infrastructure Asset Management. Transportation Research Board 97th Annual Meeting, 2018, 16p.

AMEC Environment & Infrastructure, Inc. (2013). New York State DOT Work Plan for Developing a TAMP.

Chait, Edward P. GASB 34—Methods for Condition Assessment and Preservation. NCHRP Report, Parsons Brinckerhoff; Cambridge Systematics, Incorporated, Issue 608, 2008, 133p.

Friedrichs, Kevin D. Asset Management for Kansas Counties: The State of the Practice. Kansas State University, Manhattan, 2007, 61p.

FHWA. (2017a). Asset Management Overview. Federal Highway Administration, Washington, D.C.

FHWA. (2017b). Relationships between Asset Management and Travel Demand: Findings and Recommendations from Four State DOT Site Visits. Federal Highway Administration, Washington, D.C.

FHWA. (2016). Incorporating Asset Valuation into Transportation Asset Management Financial Plans. Federal Highway Administration, Washington, D.C.

FHWA. (2014a). Distress Identification Manual for the Long-Term Pavement

Performance Program. Federal Highway Administration, Washington, D.C.

FHWA. (2014b). Life cycle assessment of pavements. Federal Highway Administration, Washington, D.C.

FHWA. (2009). Transportation Asset Management Case Studies: Life-Cycle Cost Analysis The Colorado Experience. Federal Highway Administration, Washington, D.C.

FHWA. Transportation Asset Management Case Studies: Managing and Maintaining Roadway Assets The Utah Journey. Federal Highway Administration, Washington, D.C.

Frangopol, D. M. (2011). Life-Cycle Performance, Management, and Optimization of Structural Systems under Uncertainty: Accomplishments and Challenges. *Structure and Infrastructure Engineering,* 7(6), 389-413. doi:10.1080/15732471003594427.

Garvin, M. J., & Bosso, D. (2008). Assessing the Effectiveness of Infrastructure Public-Private Partnership Programs and Projects. *Public Works Management & Policy,* 13(2), 162-178. doi:10.1177/1087724x08323845.

Garvin, Michael J. Does Bringing Infrastructure Onto the Balance Sheet Matter? An Overview of Public Water Enterprise Financial Reporting Practices. American Society of Civil Engineers, 2008, pp 8-15.

Hale, Joanne E; Hale, David P; Sharpe, Shane. Asset Management GASB 34 Compliance Phase III (Bridges). University of Alabama, Tuscaloosa; University Transportation Center for Alabama; Alabama Department of Transportation; Federal Highway Administration, 2007, 175p.

Halfawy, M. R. (2008). Integration of Municipal Infrastructure Asset Management Processes: Challenges and Solutions. *Journal of Computing in Civil Engineering,* 22(3), 216-229. doi:10.1061/(asce)0887-3801(2008)22:3(216).

Hard, Edwin; Brian S. Bochner, Yingfeng (Eric) Li, Yi (Grace) Qi, Ivan Damnjanovic, William E. Frawley. Preserving the Functionality/Asset Value Of The State Highway System: Technical Report. Texas A&M Transportation Institute. February 2010.

Kim, J., Chen, C., & Ebdon, C. (2018). Effects of the GASB No. 34 infrastructure reporting standards on state highway infrastructure quality: A panel data analysis. *Journal of Public Budgeting, Accounting and Financial Management, 30*(2), 191-210. doi:10.1108/JPBAFM-06-2018-027.

Lambert, J. H., Wu, Y., You, H., Clarens, A., & Smith, B. (2013). Climate Change Influence on Priority Setting for Transportation Infrastructure Assets. *Journal of Infrastructure Systems,* 19(1), 36-46. doi:10.1061/(asce)is.1943-555x.0000094.

Landers, K. (2010). The new paradigm. *Better Roads, 80*(8), 10-15.

Oklahoma Department of Transportation (2019). Project Development Process. Retrieved from: http://www.okladot.state.ok.us/projmgmt/contracts/pdfs/pmd_project-dev-process.pdf

Oklahoma Department of Transportation (2018). Transportation Asset Management Plan. April 2018.

Osei-Kyei, R., & Chan, A. P. (2015). Review of Studies on the Critical Success Factors for Public-Private Partnership (PPP) Projects from 1990 to 2013. *International Journal of Project Management,* 33(6), 1335-1346. doi:10.1016/j.ijproman.2015.02.008.

Puffer, Willard; Freeman, Jackie; Jackson, William J. A Scalable Pavement Rating and Management System for Government Agencies. Seventh International Conference on Managing Pavement Assets, 2008, 12p.

Stalebrink, Odd J. Infrastructure Reporting in Small and Rural Local Governments: The Case of West Virginia. American Society of Civil Engineers, 2008, pp 99-107.

Texas A&M TTI (2019). Urban Mobility Report 2019. Retreieved from https://mobility.tamu.edu/umr/congestion-data/

TRIP. (2017). Oklahoma Transportation by the Numbers: Meeting the state's need for safe, smooth, and efficient mobility. Washington, D.C.

Zhang, H., Keoleian, G. A., & Lepech, M. D. (2013). Network-Level Pavement Asset Management System Integrated with Life-Cycle Analysis and Life-Cycle Optimization. *Journal of Infrastructure Systems,* 19(1), 99-107. doi:10.1061/(asce)is.1943-555x.00000093.