Pavement Asset Management

Pavements Branch

WSDOT

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Pavement Asset Management

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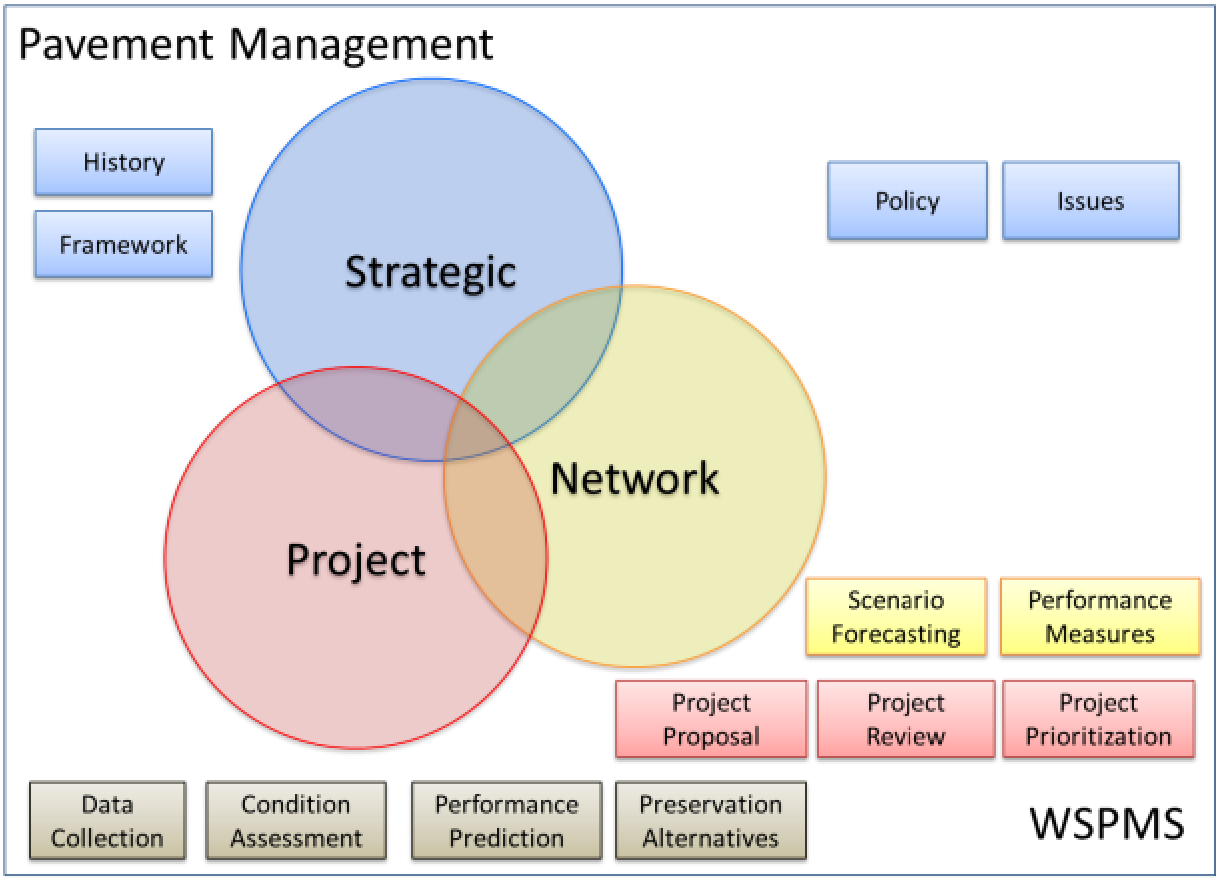
Pavement Management is a systematic approach to providing, evaluating, and maintaining pavement assets requiring decision making at strategic, network and project levels.

Successful Pavement Management has two fundamental characteristics. The first is strong communication between decision makers at different decision levels. The second is a robust Pavement Management System. WSDOT has a long history of Pavement Management and is considered a national leader in both of these respects.

The purpose of this document is to provide an informative overview of Pavement Management at WSDOT.

Contents

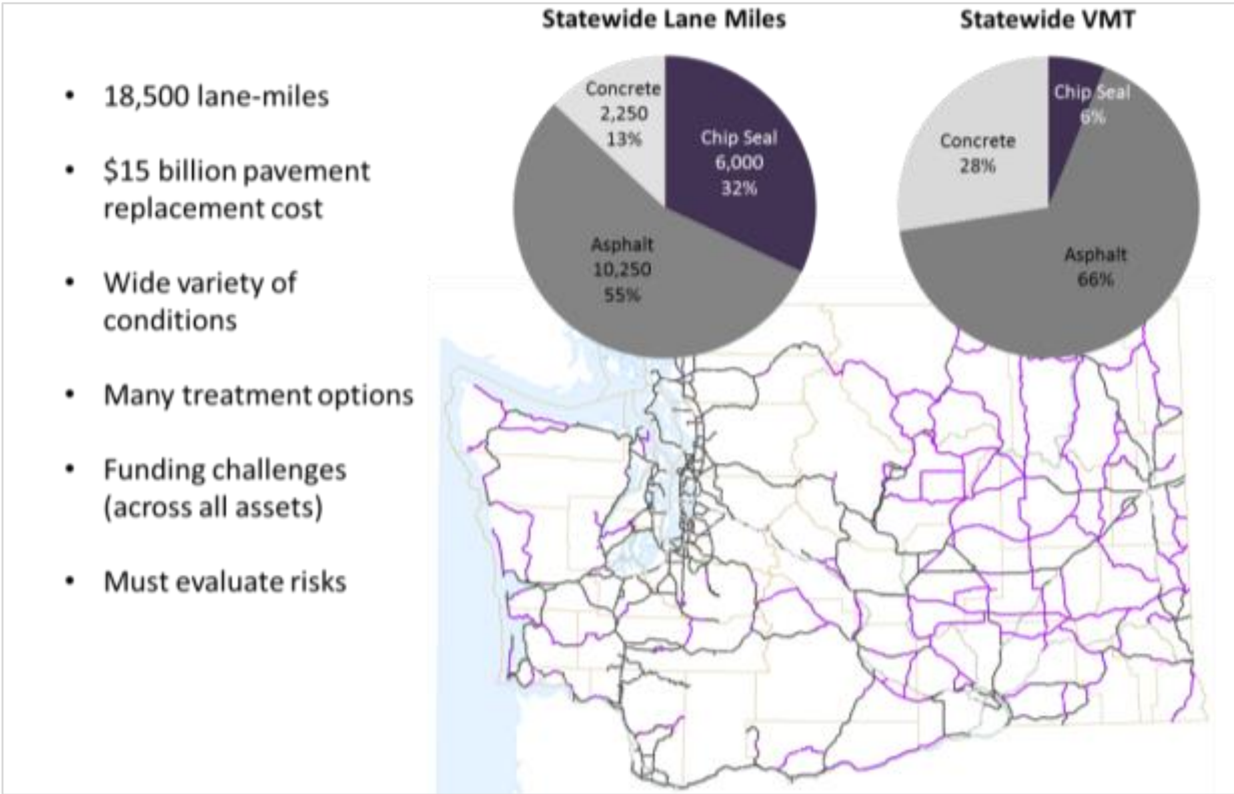
Overview



Pavement Management decisions occur at all levels of WSDOT, which can be broadly divided into Strategic, Network, and Project levels. These decisions are interconnected. Project decisions are driven by strategic decisions, which directly affect the network level reporting that occurs, and the network analysis in turn affects the strategic level.

This document starts by giving a broad overview of the pavement management strategy at WSDOT in the context of its scope and history. After the broad context of Pavement Management is established, an overview of the project preservation process is covered, starting with Data Collection and continuing through project prioritization and programming. After this project level view, a network level view of pavement management is presented including scenario forecasting and performance measures. Finally, Pavement Management will be brought full circle with a look at the issues facing Pavement Management and potential policy to further establish its direction.

Pavement Management Perspective

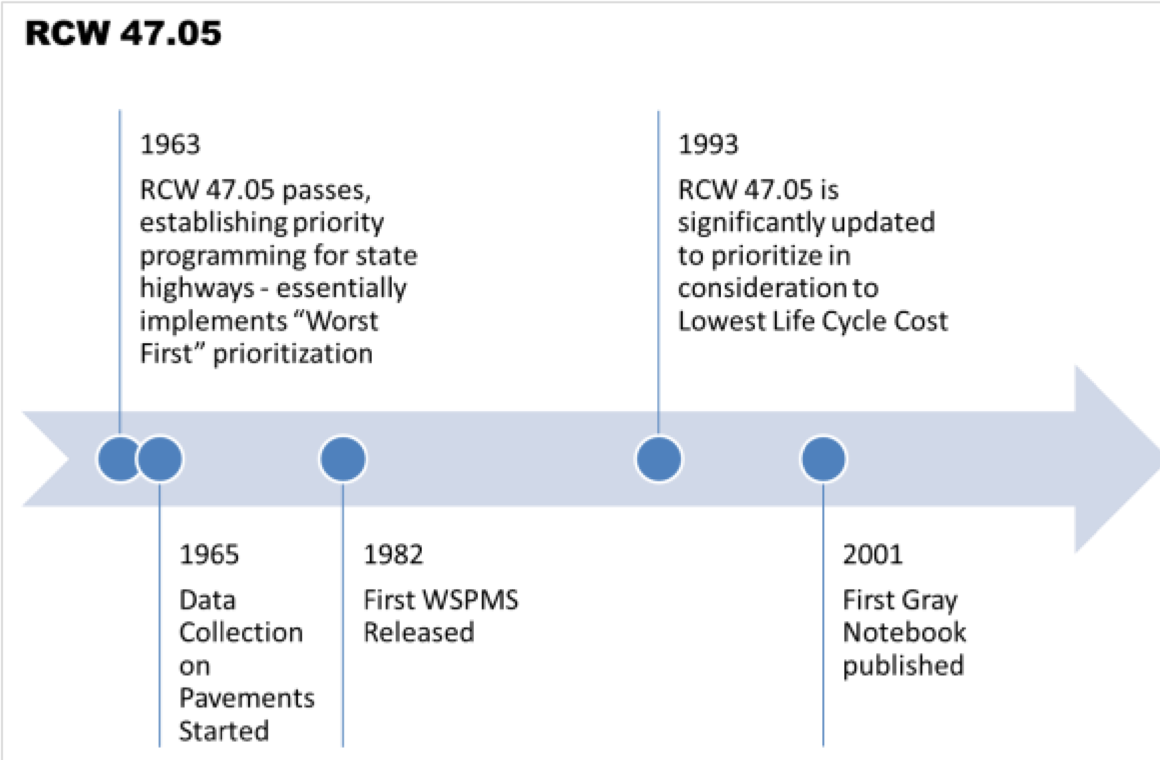


WSDOT manages over 18,500 lane miles of mainline pavement, with over 2,000 additional special use and ramp lane miles. For just the pavement structure alone, these pavement assets alone are over a $15 billion investment. These lane miles are spread over Washington's diverse geography and subject to a wide variety conditions such as environment and traffic. To effectively manage these roadways, WSDOT uses many treatment options to maximize pavement life for each unique roadway. Getting the right fix at the right time is achieved through continuous innovation and performance monitoring.

In many ways, this is analogous to a managed health care system. Performance trends and predictions can be useful for managing an entire network of patients. They cannot, however, be used to make customized health plans for each unique individual within the network. This must be achieved with regular health checkups. Similarly, the Pavement Management at WSDOT combines annual pavement condition surveys along with innovation and performance trends to make the best decisions at all levels.

Currently, there is severely inadequate funding available to cost efficiently preserve these valuable pavement assets. It becomes even more important for WSDOT to evaluate risks, predict investment trade-offs, and effectively communicate during this time in order to maximize cost effectiveness while securing the funding needed to continue to deliver safe and reliable roadways.

RCW 47.05



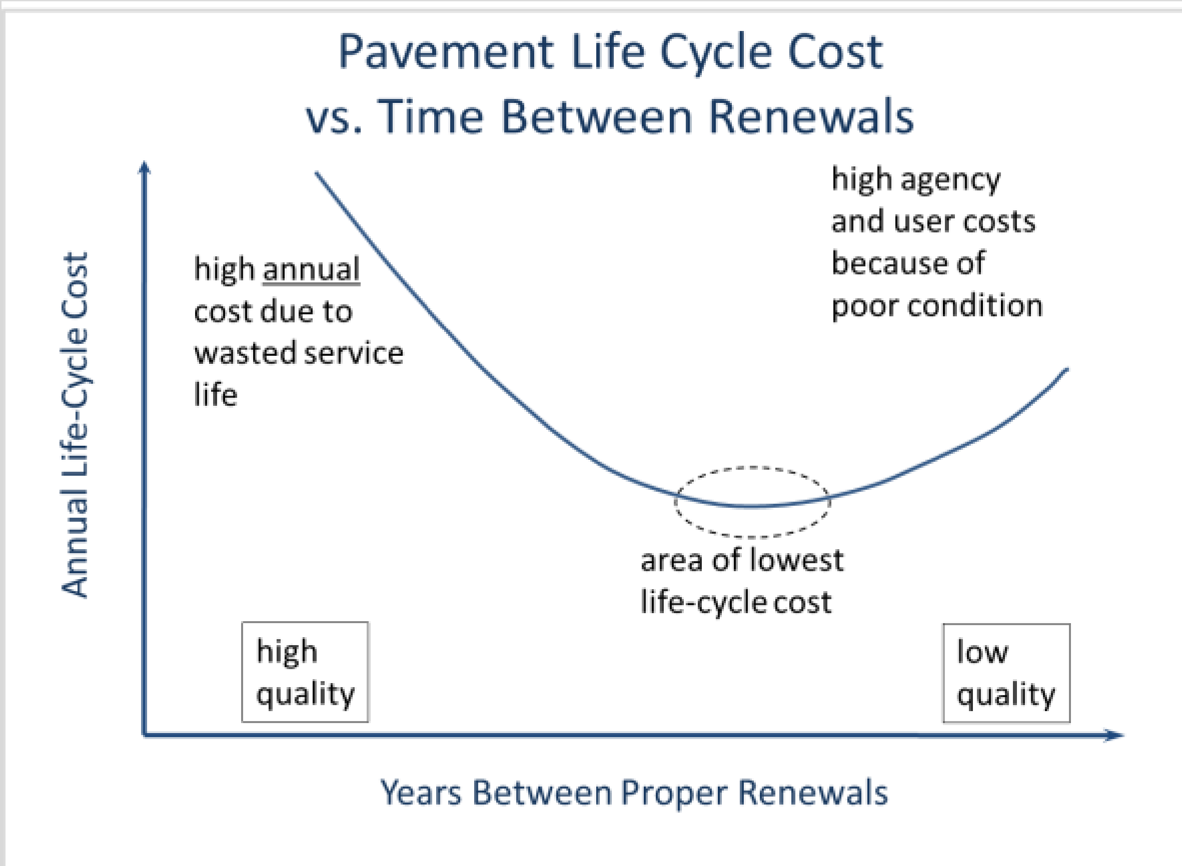
WSDOT has a long history of pavement management, which began its evolution in 1963 with the passage of RCW 47.05 Priority Programming for Highway Development. Essential language from the Declaration of Purpose:

"…it is the purpose of this chapter to establish a policy of priority programming for highway development having as its basis the rational selection of projects according to factual need, systematically scheduled to carry out defined objectives…and fixed in advance with reasonable flexibility to meet changed conditions".

This prompted a systematic data collection which started in 1965 and fully formalized in 1969, making WSDOT one of the longest running pavement management programs. The Washington State Pavement Management System (WSPMS) was developed in the late 1970s to analyze and interpret pavement information, which makes it one of the longest running Pavement Management Systems,

The culture of innovation at WSDOT is long standing, and RCW 47.05 was significantly modified in 1993 to fit an asset management framework and put the asset management principle of Lowest Life Cycle Cost as the most effective pavement management. In other words, instead of trying to provide the best possible roadways within a given budget, the objective changed to finding the most cost effective way to provide a safe and reliable transportation system. This is the same objective for Pavement Management today.

Lowest Life Cycle Cost



Managing by Lowest Life Cycle Cost is the primary objective of Pavement Management. WSDOT has been a strong innovator in employing the principles of asset management within a State DOT. The fact that WSDOT was able to push Life Cycle Costs in the early 1990s, and get it within an RCW, speaks to this innovation.

The concept of life cycle costs, and finding the lowest one, is straightforward. The Life Cycle Cost (LCC) is defined as the total cost of ownership over the whole life of an asset. When there are different alternatives to manage an asset, choosing the one with the lowest Life Cycle Cost is referred to as the Lowest Life Cycle Cost. For pavements, this concept is shown above. If rehabilitation is done too early, pavement life is wasted. If rehabilitation is done too late, very costly repair work may be required, especially if the underlying structure is compromised, and the user incurs higher fuel and ownership costs.

In essence, the objective function of LLCC is to meet a minimum acceptable performance at the lowest possible annual cost. For WSDOT, this is the most practical asset management objective function. Alternative objective functions might be: “What is the best possible condition that can be achieved at a specific level of funding?” or “Given a specific level of funding, how many of the worst roads can be fixed?” These alternatives put overall system condition and fixing poor roads at the highest priority. However, using lowest life cycle cost makes cost efficiency the highest priority.

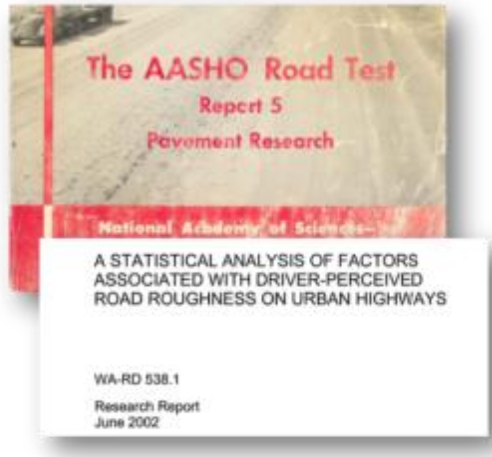
Minimum Acceptable Performance

Over 50 years of research has looked at pavement performance from the perspectives of:

- Driving Public
- Commercial Freight
- Vehicle Operating Cost
- Pavement Structure
- Safety

Early 1960's -

Early 2000's -



Resulting in primary condition indicators of :

- **Cracking**
- **Rutting**
- **Roughness**
- **Skid Resistance (Friction)**

One of the fundamental questions within the Lowest Life Cycle Cost framework is establishing the minimal acceptable performance levels. There is over 50 years of both national and WSDOT research analyzing pavement performance from many perspectives including:

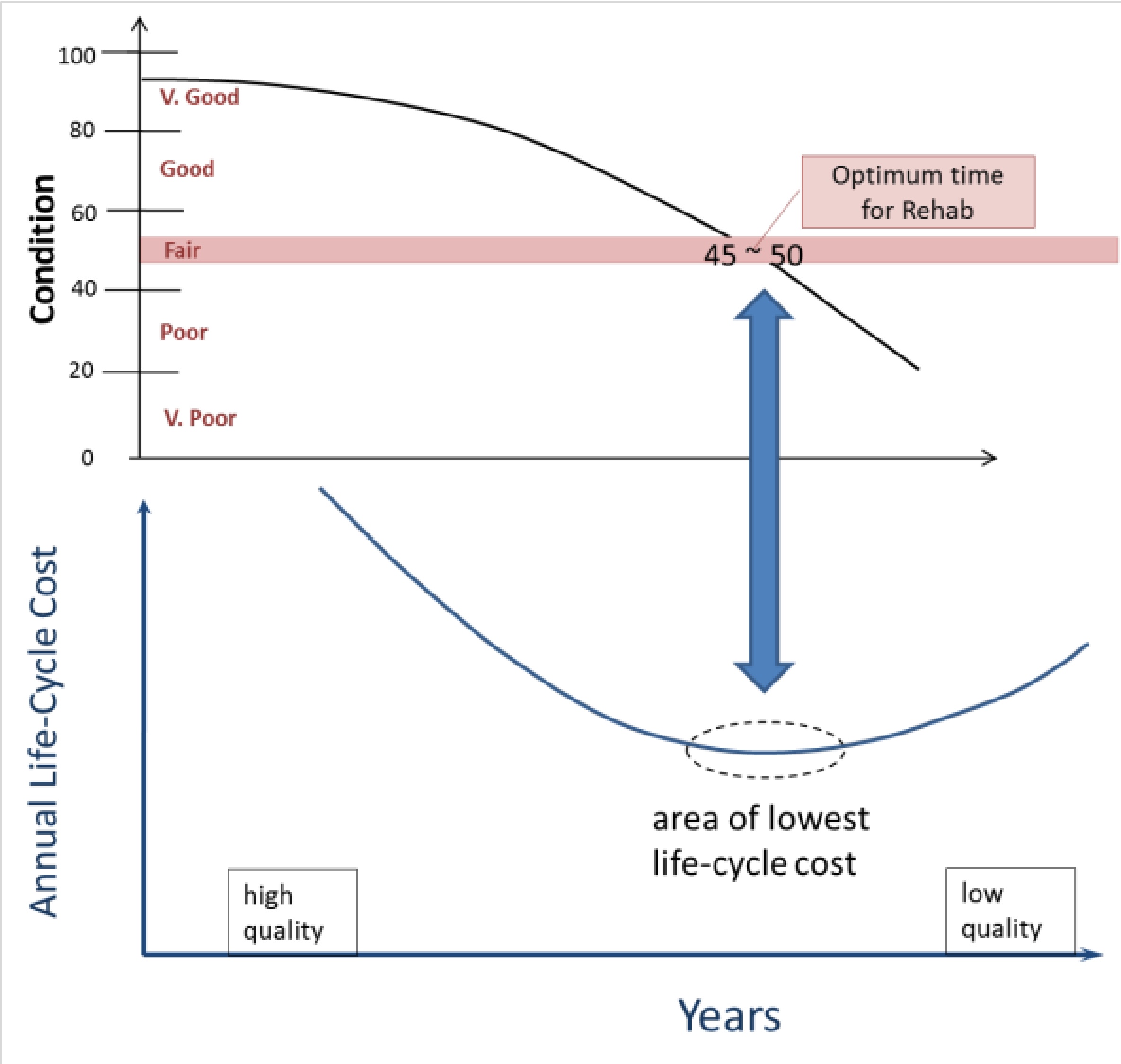
- The Driving Public
- Commercial Freight
- Vehicle Operating Cost
- Pavement Structure
- Safety

All of this information has led WSDOT to use a several condition indicators, including:

- Cracking
- Rutting
- Roughness
- Skid Resistance (Friction)

These are used to set the minimum acceptable performance levels on the WSDOT system. Roads that are below these minimum acceptable performance levels are categorized as "Poor". Roads that are above are categorized as "Good". WSDOT has been using more categorizations to help distinguish pavement performance, by including "Very Good", "Good", and "Fair" breakdowns for pavements above the minimum threshold, and "Poor" and "Very Poor" for pavements below.

Pavement Quality and LLCC



There is a direct relation between the overall pavement quality and Lowest Life Cycle Cost. When more funding is spent than required by LLCC, overall pavement quality is higher but pavement life is considered wasted. When less funding is spent than required by LLCC, overall pavement quality is lower and a liability is accrued to move the pavement back to acceptable levels, making life cycle costs increase.

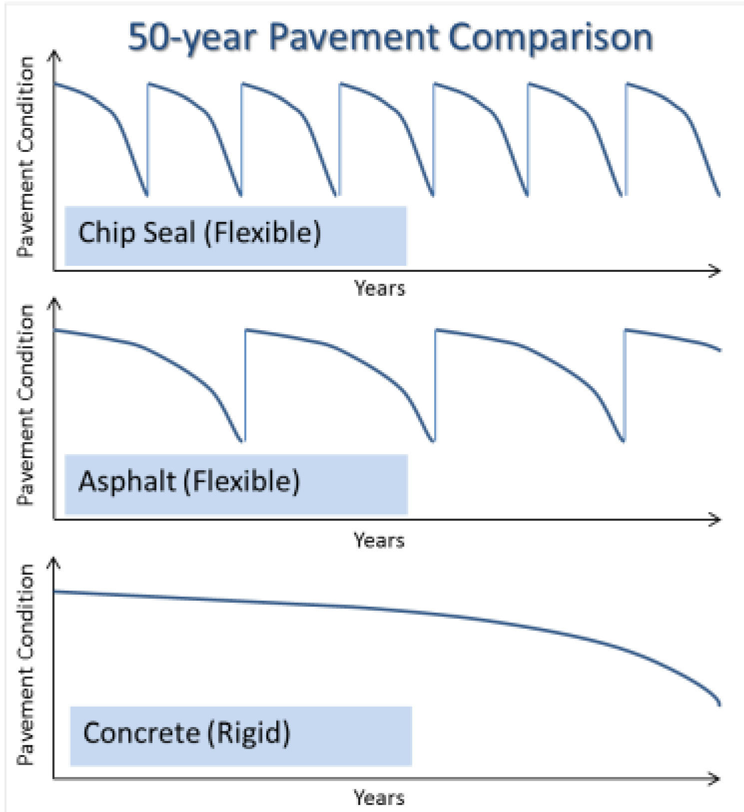
Pavement Models: Flexible and Rigid

Flexible pavements

- Asphalt or chip seal
- Managed in cycles
- Emphasis is to limit scope of work to only resurfacing

Rigid pavements

- Concrete pavements managed as long-term structures
- Eventually must be reconstructed.

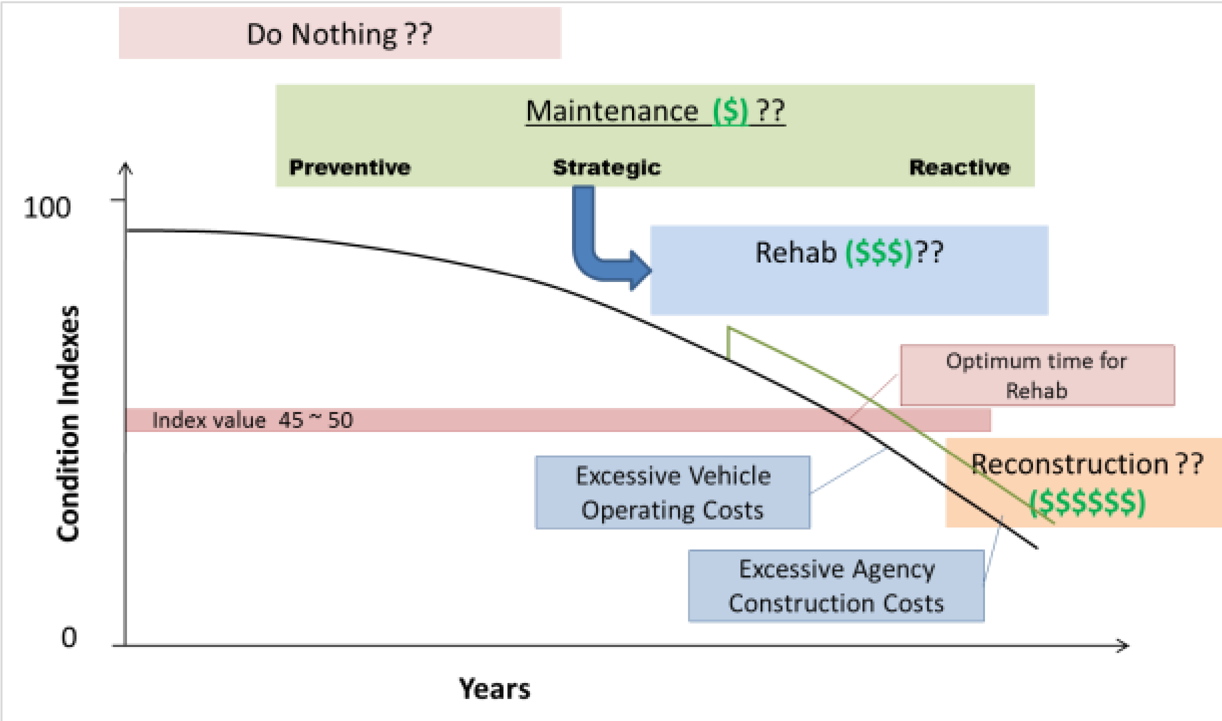


Understanding the basic life cycles of flexible and rigid pavements is an essential starting point for understanding cost effective Pavement Management.

Flexible pavement includes chip seal and asphalt materials. When a flexible pavement structure is put into place, it is designed with enough thickness to carry expected traffic loads for 50 years, as long as there are periodic surface renewals. When sufficient structure is in place to carry traffic loads for 50 years, WSDOT has found that these structures can essentially be modeled perpetually as long as they are monitored and resurfaced at the right time. This results in the Lowest Life Cost for these structures.

Rigid pavement is referred to solely by “concrete” at WSDOT. Concrete pavements are also designed to carry traffic loads for 50 years. Unlike flexible pavements, there are currently no cyclical resurfacing strategies for concrete, and at some point a type of reconstruction or major overlay is inevitable.

LLCC: Asphalt and Chip Seal

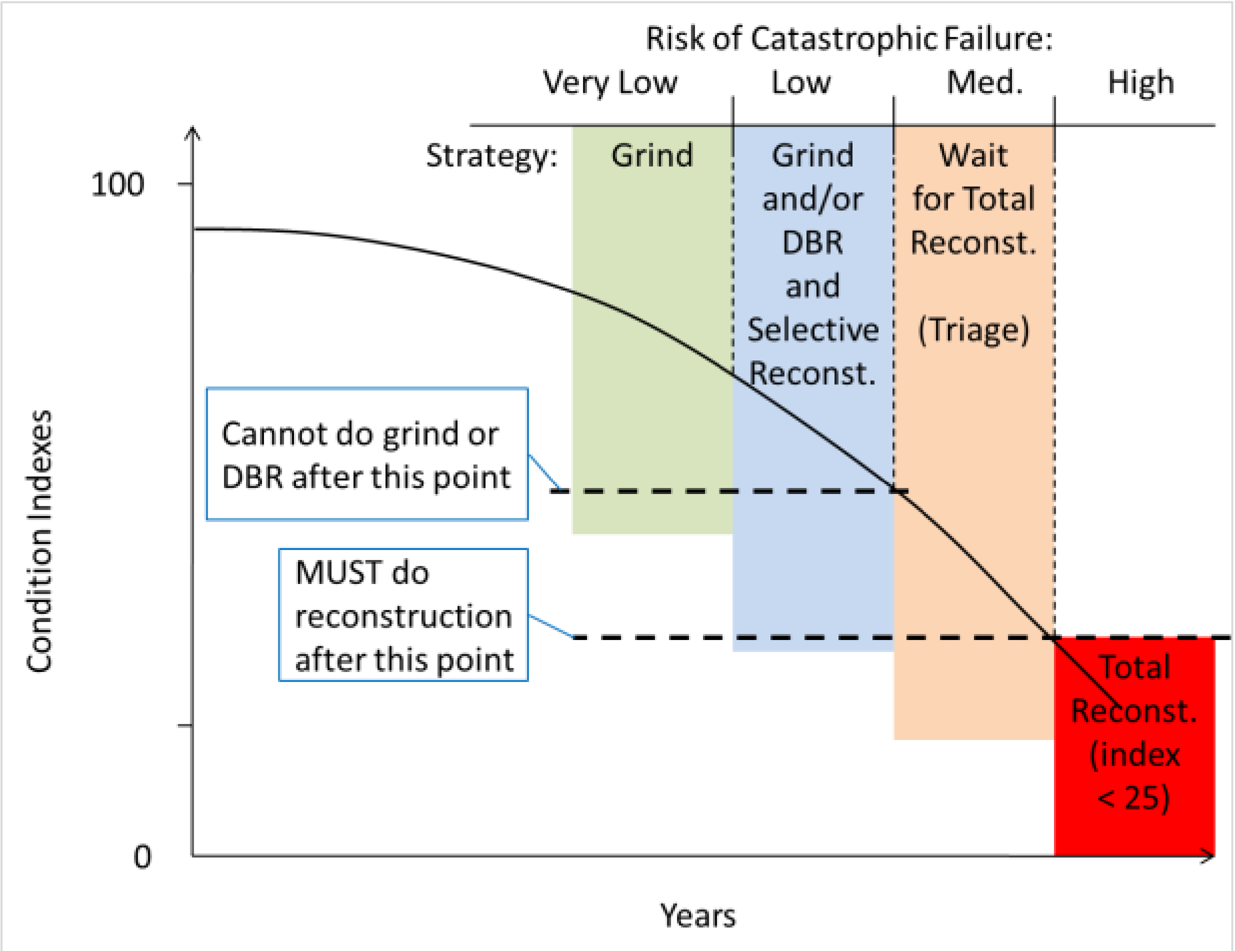


Pavement Preservation for asphalt and chip seal roadways at WSDOT is generally thought of in terms of one cycle of surface life. This is shown in the graphic above, with the black curve being a traditional representation of pavement deterioration. Also shown are the choices and consequences throughout this life.

The most cost effective decision is determining the optimal time to resurface the roadway. This is because pavement distresses are usually located at the surface of the pavement structure, making a resurfacing all that is needed to correct these pavement defects and renew carrying capacity of the pavement structures. If the resurfacing is done too early, pavement life is wasted. If the resurfacing window is missed, more costly rehabilitation and eventually reconstruction, which is extremely costly, must be done to create a safe and reliable pavement structure. Moreover, pavements that are past the time to properly resurface are generally in poor condition and users incur increased vehicle operating costs due to higher fuel consumption and increased vehicle and tire wear.

Performing maintenance activities is one strategy that WSDOT is aggressively employing and researching to become more cost effective. Performing maintenance before and during the resurfacing window creates a new, longer effective surface life which lowers the overall annual preservation costs. Furthermore, maintenance performed after the proper resurfacing (which is not as cost effective as proper resurfacing timing) is still essential because it increases the time before reconstruction is inevitable and makes a safer and more reliable pavement.

LLCC: Concrete



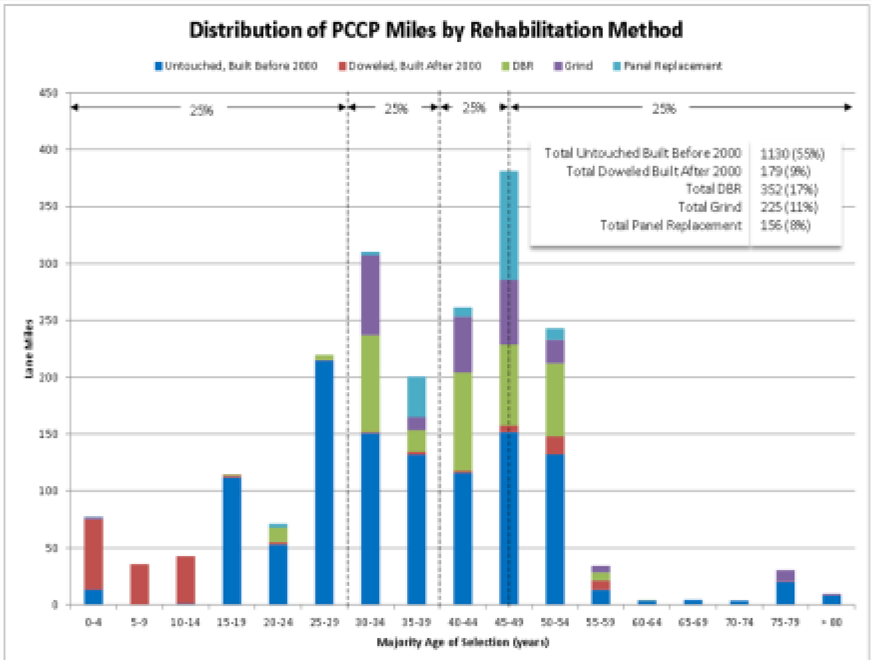
As previously mentioned, concrete does not follow the cyclic model used to manage flexible pavements. Shown above is a traditional pavement deterioration curve along with the choices and consequences throughout a concrete pavement's life.

Because a type of reconstruction is inevitable, maximizing the life before reconstruction is the most cost effective way to manage concrete.   However, life extension must be made in consideration of the minimum acceptable performance and the risk of catastrophic failure. In other words, when a concrete roadway is initially considered in need of reconstruction, it is generally modelled that no additional rehabilitation penalty is assessed for waiting, such as with flexible pavement reconstruction. However, these roads are less likely to be in acceptable performance condition and more likely for catastrophic failure, which is an event that compromises the safety and reliability of the pavement and forces immediate action.

Several additional factors must be taken into consideration when managing concrete roads. These factors include the high capital cost, the long period between reconstruction activities (50+ years) and the durability of concrete in urban and mountainous areas.

Concrete Network

- Concrete pavements are in high-priority locations
- 50% of concrete is over 40 years old
- Reconstructing 10% of concrete network is $500 million



The scope and age of the WSDOT concrete network is especially important in the immediate future. The majority of concrete roadways were built in the 1960s as part of the Interstate system. This means that not only are concrete pavements in high priority locations, but also that over 50% of the concrete is over 40 years old.

Therefore, the concrete network at WSDOT is at an especially critical time in its life. Imminent reconstruction needs must be balanced and prioritized against available funding and future risk.

Annual Pavement Cost

Treatment	Added Life (Years)	Typical Construction Cost*	Typical Annual Cost*
Maintenance	2-4	$5,000	$1,500
Chip Seal Rehab	6-7	$40,000	$7,000
Asphalt Rehab	10-17	$250,000	$18,000
Concrete Grind	10-15	$175,000	$15,000
Concrete Dowel Bar Retrofit	15-20	$600,000	$35,000
Concrete Reconstruction	50-60	$2,500,000	$45,000

* Per lane mile

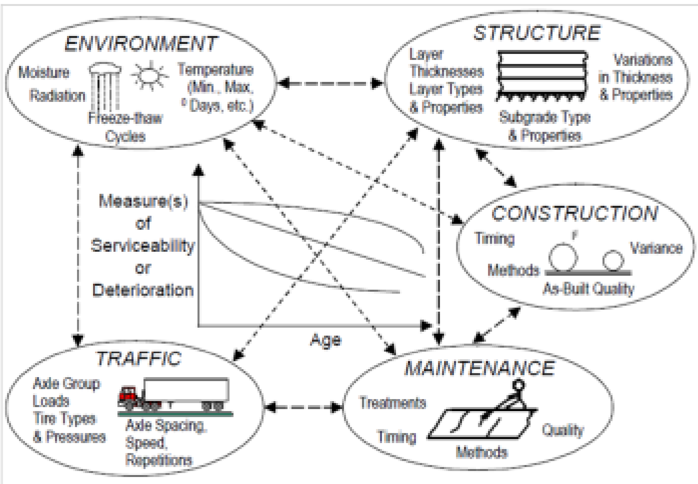
A fundamental part of understanding cost efficiency and pavement models is getting relative annual costs for preservation activities. Shown above are typical annual costs for pavement preservation activities. The first three activities are applicable to flexible pavements while the last three activities are applicable to concrete pavements. It is also ordered from lowest to highest annual cost.

A very important condition for the accuracy of this table is that the treatments must approach the added life to achieve the annual costs. For example, chip seal resurfacing is best placed on lower volume roads (generally 5,000 AADT or less, but also applicable up to 10,000 AADT). If it is placed on high volume roadways, such as a busy Interstate, it may only add 1 year of life, at best. This drastically increases the annual cost. Therefore, this table assumes that the treatments are appropriate for the section it is being applied to.

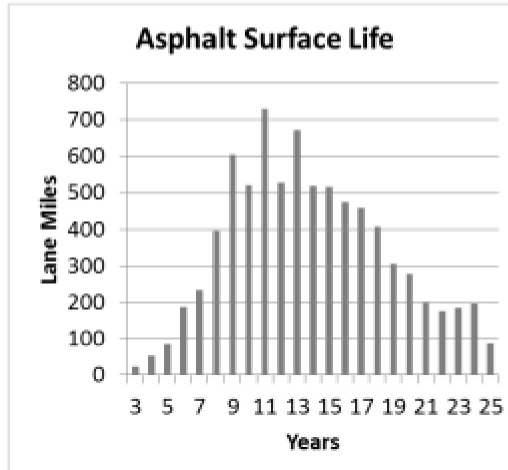
Variability

Significant variability in pavement life due to variability in conditions

This variability in performance is the key reason that pavement monitoring and site specific analysis is so important to achieve Lowest Life Cycle Cost



Factors affecting pavement performance (after Haas 2001)



Variability in asphalt surface life for WSDOT

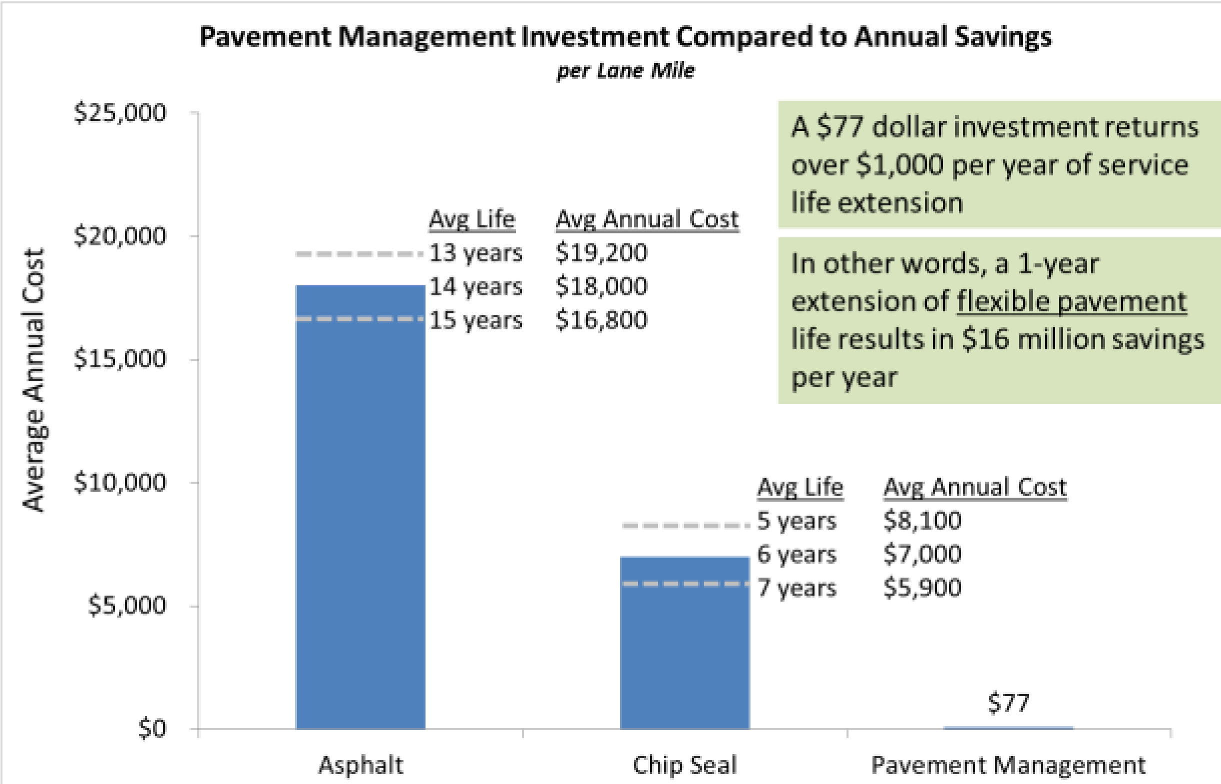
There are several interrelated factors affecting pavement performance including Environment, Traffic, Structure, Construction and Maintenance (as shown in diagram above-left). This is manifested into a wide distribution of pavement life, with a primary example being the distribution of surface life at WSDOT. In other words, even though 14.9 years is the average life of an asphalt surface, actual site-specific life can have a broad range from 8 to 20+ years.

The many variables affecting pavement life directly correlates to WSDOT annual measurement of pavement data. Having site specific information is the key to managing pavements within the lowest life cycle cost framework.

Additionally, Pavement Management analyzes this variability in the context of methods, procedures and historical performance. This allows the review of:

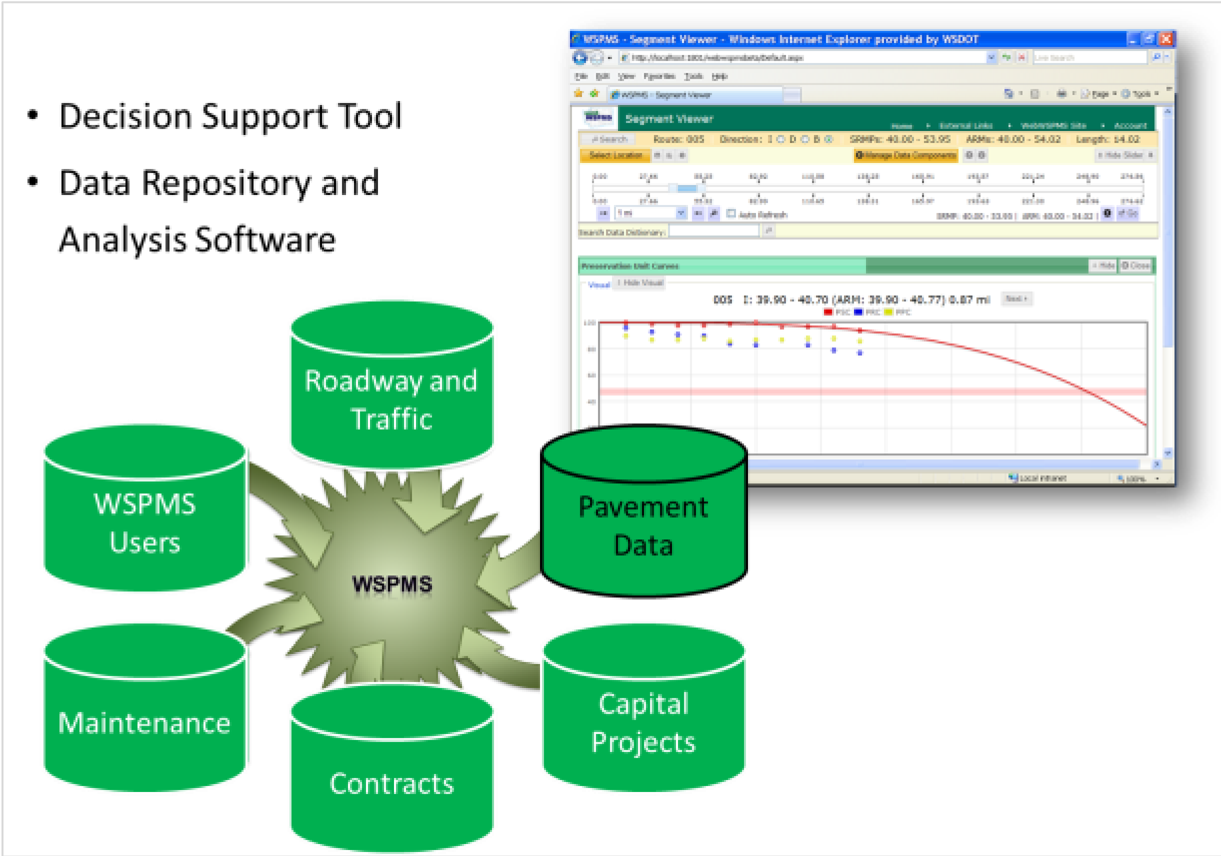
- Methods that provide best value
- Locations that have unusually high, or low, annual cost
- Poorly performing contracts
- Best management practices (region and statewide)

Value of Decision Analysis



Having site specific information is fundamental to the WSDOT methodology for implementing Lowest Life Cycle Costs. However, there is a cost to monitoring and analyzing the site specific information used by Pavement Management. The above graph shows the relative scale of annualized costs for asphalt and chip seal, along with the amount of savings with a change in service life. Finally, the average cost per lane mile for pavement management is shown. It could be easily stated based on the scales of costs and the historical impact of Pavement Management on WSDOT that it has a cost benefit ratio of over 10, making it an easily justifiable cost for such a large benefit.

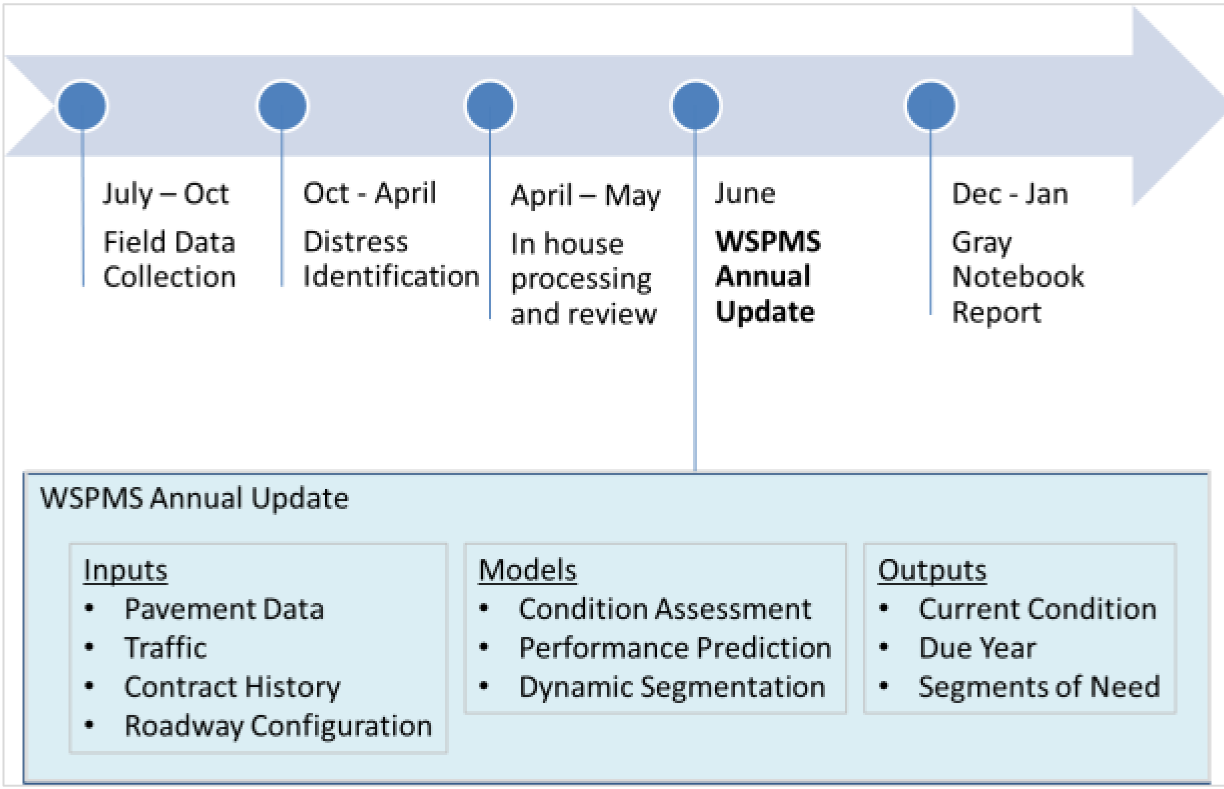
WSPMS



The Washington State Pavement Management System (WSPMS) is the primary tool used for Pavement Management at WSDOT. The first version was developed in the late 1970s with the support of FHWA. It was implemented within WSDOT in 1982. The in-house development of WSPMS continues today, with the primary WSPMS tool the intranet site *WebWSPMS*.

Two fundamental properties define the WSPMS. The first is that it uses *site-specific analysis* to build Pavement Management decision making from the bottom up. The second property, annual measurement and update, was implemented in 1988 (previously biannual). Building upon these properties has allowed WSDOT to continuously be a national leader in Pavement Management.

WSPMS: Annual Update Overview



Much of the information in the WSPMS is updated as part of an annual process. This process starts in July of the previous year and culminates in early June when a new version of WSPMS is released. The annual update of the data can be thought of as an instantaneous process, in which the inputs are analyzed using well-established models to create meaningful outputs to aid decision makers.

The inputs, models and outputs are detailed in the graphic above. The primary input covered in this document is the collection of pavement data, which is covered in the following sections. Other inputs are imported into the WSPMS from other business areas in the Agency. After an understanding of data collection, the pavement models and pavement outputs are covered before putting this information in the context of P1 Project Workflow.

Pavement Management Process: From Data Collection to Project

Data Collection

Data Collection

- Pavement Survey Van
  - Images (Windshield and Pavement)
  - Roughness
  - Rutting
  - Faulting
- Friction Testing Truck and Trailer
  - Friction

Pavement Survey Van

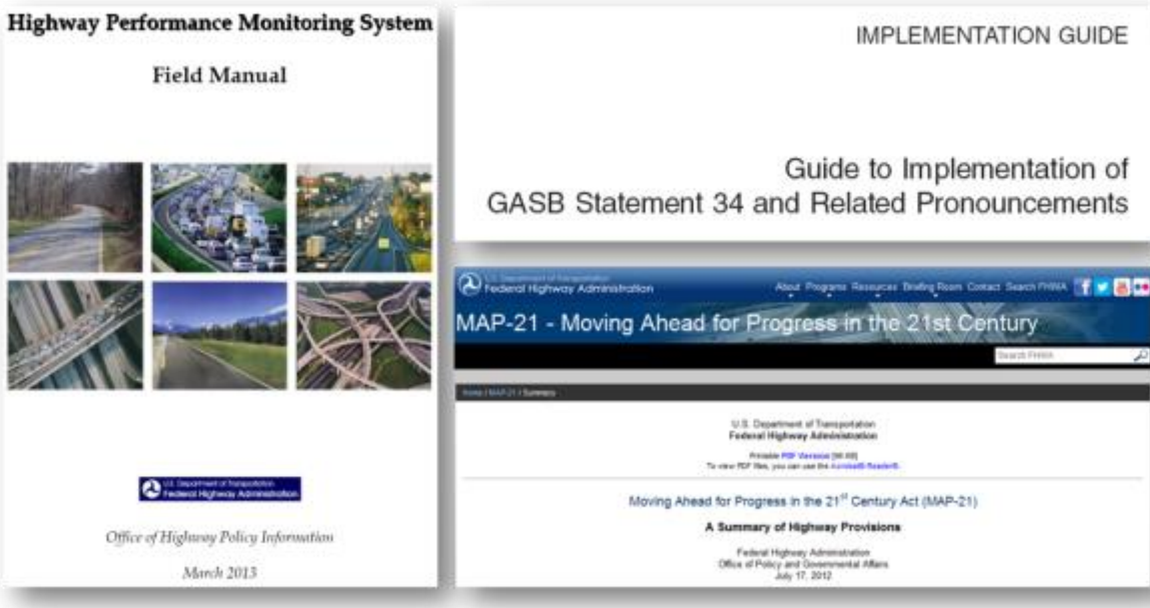
Friction Testing Truck and Trailer

The Pavements branch of the Materials Laboratory is responsible for collecting the information needed to assess the condition of the WSDOT maintained roadways. Currently, this involves two types of specialized vehicles; a Pavement Survey Van and a Friction Testing Truck and Trailer. The information used as part of the WSPMS is all collected using the Pavement Survey Van, while the Friction information is used as part of the Skid Collision Reduction Program, as directed by Official Policy P 2035.

The roughness, rutting and faulting information is automatically produced based off of standardized calculations from longitudinal and transverse profiles collected from the van. The imagery, windshield and pavements, are used to manually categorize deficiencies in the roadway surface. While the manual categorization of distresses is time consuming, it has been proven to be much more efficient and accurate than historical windshield surveys.

Further information is found in sections on roughness, rutting, faulting and distress identification.

Federal Reporting Requirements



WSDOT collects data to provide the basis for effective Pavement Management. In other words, WSDOT has been collecting data prior to federal requirement because it is a best practice. However, it is also important to get a broad perspective for what information is required for federal reporting. While the Moving Ahead for Progress 21 (MAP-21) performance measures will be shortly defined, there are already two existing avenues for federal reporting. The first is the Highway Performance Monitoring System (HPMS) and the second is the Government Accounting Standards Board Statement No. 34 (GASB 34).

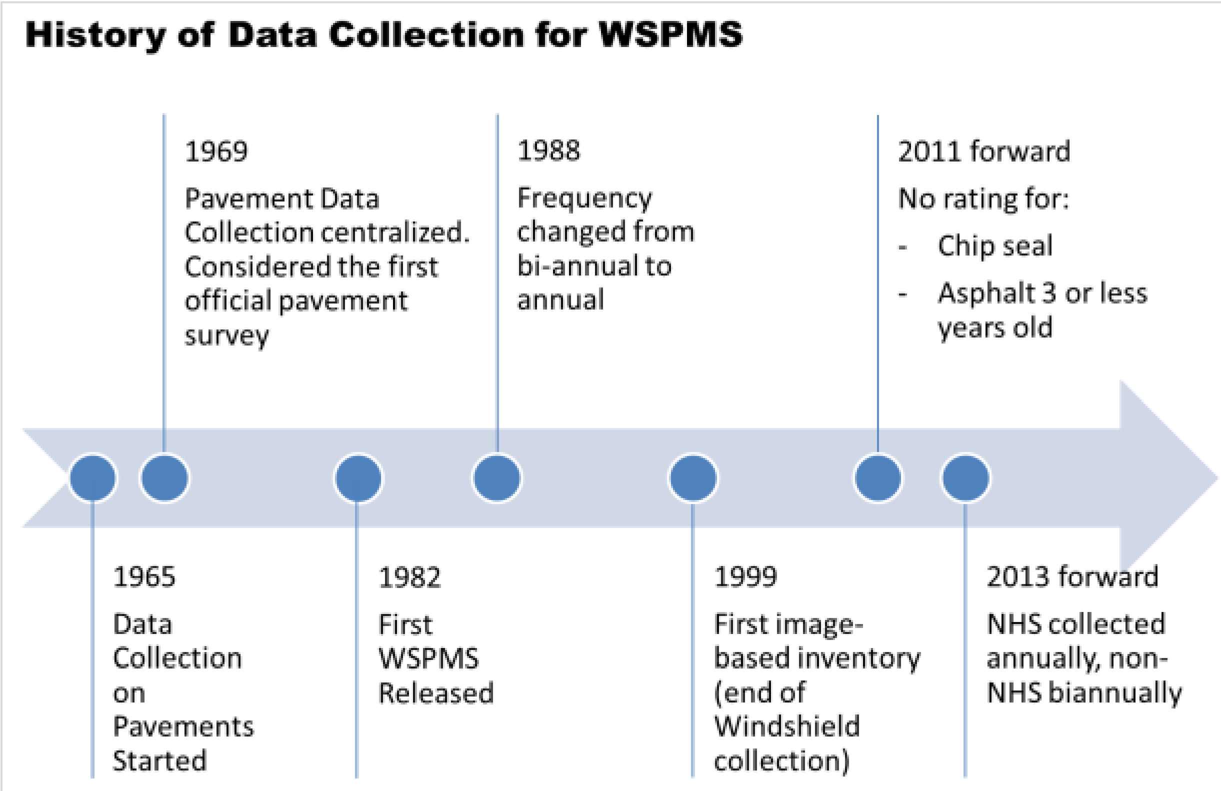
As mandated in the HPMS Field Manual Chapter 4.4 WSDOT is required to report:

- IRI annually for the National Highway System (NHS) and on a 2-year maximum cycle for other HPMS sections
  - Corresponds to 74% of the WSDOT system biannually and 51% annually
- Rutting, Faulting and Cracking are required for HPMS Sample Sections on a 2 year cycle
  - Corresponds to 32% of the WSDOT system

GASB 34 was introduced in 1999 with the intent to show how financially effective state and local entities have been in managing their assets. For WSDOT, the modified approach of reporting was used, and the 85% Fair or Better threshold was used as the benchmark for effective pavement asset preservation. Every other year the percentage of fair and better roads is reported as part of the GASB 34 reporting requirements.

MAP-21 is new legislation requiring performance and risk-based asset management. The proposed rules were released and evaluated during 2015. Finalized rules are expected in mid to late 2016. Further information is available at http://wsdot.wa.gov/accountability/MAP-21.

Data Collection: History and Frequency

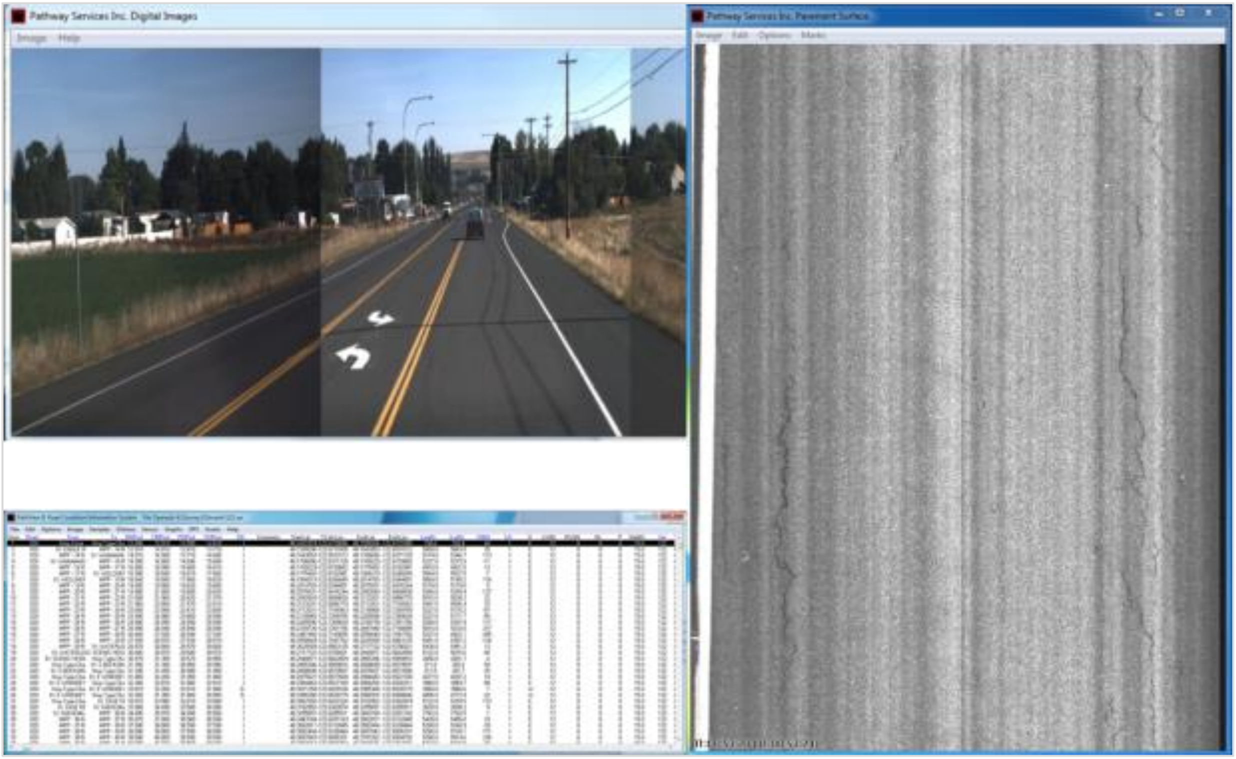


Pavement data collection has evolved since its first inception at WSDOT in 1965, due to both improvements in technology and pavement management practices. The earliest surveys, done in 1965, 67 and 68, were not completed by a centralized office. This decentralization was characterized by sufficient discrepancies between personnel, which prompted the change to centrally collect data by crews based at headquarters. This centralization continues today and the pavement data collection is completed by the Pavements branch at the State Materials Laboratory.

In 1988, in response to the need for more accurate assessment and predictive capabilities in the WSPMS, the windshield survey was switched from a biannual basis to an annual basis. Annual data collection has proven itself more accurate than biannual collection, to the point where the relatively small upfront collection costs are more than repaid in improved decision making. Effect of Frequency of Pavement Condition Data Collection on Performance Prediction is a recent FHWA study supporting annual collection, especially for distress information.

In 1999, the windshield survey was replaced with an automated collection of imagery which is then processed manually. This is referred to as semi-automated collection. In addition to increased safety, this methodology is more accurate and efficient than the previous windshield survey. Transition from Manual to Automated Pavement Condition Surveys: Washington State's Experience provides in-depth background and analysis on using the semi-automated collection versus the older windshield survey.

Data Collection: Methodology



An screenshot of the PathView software used to view and process collected pavement data

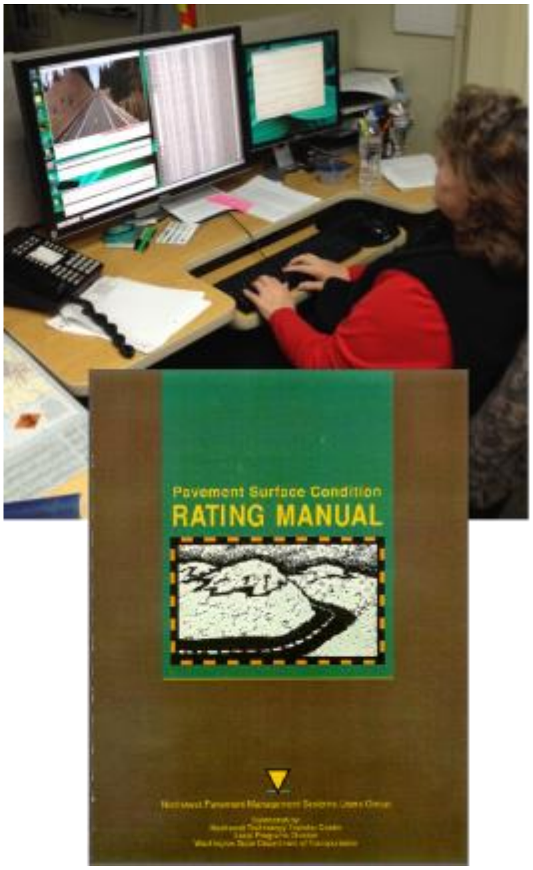
There are two distinct phases in the pavement data collection. The first phase is the in-field collection of the sensory data collected in the Pavement Survey Van. The second is the manual rating of the images, which is the process to categorize the distresses visible in the pavement images.

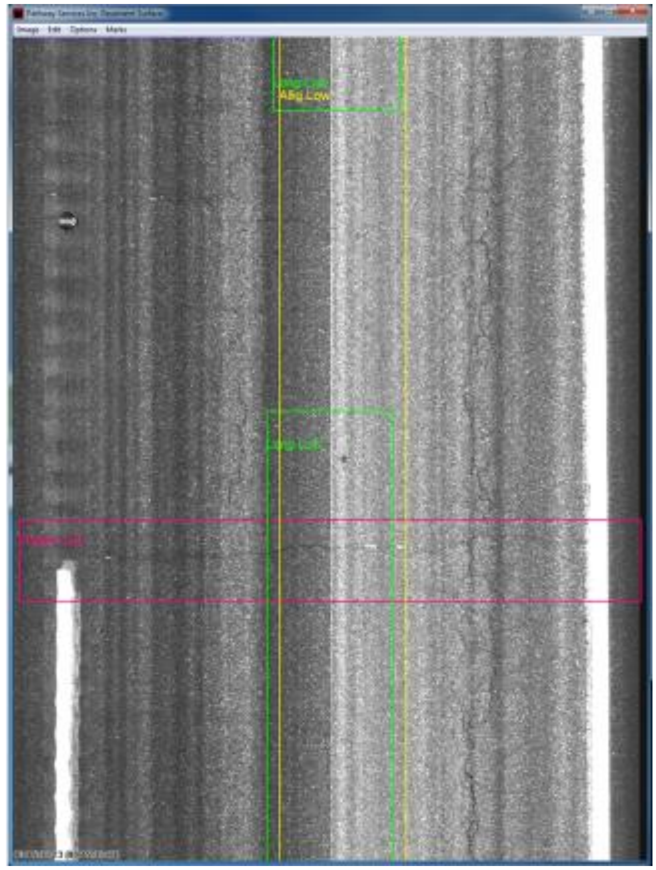
Data collected in the Pavement Survey Van is collected in one lane, and then applied to adjacent lanes. Protocol is based on collecting the lane with the most truck traffic, which also is expected to be in the worst condition. The specific protocol is:

- One lane driven if there are 3 or less lanes (not including turn lanes) and the roadway is not divided (i.e. no median or functional separation of pavement)
    - The direction of travel was developed in collaboration between regional personnel and headquarters during the switch between windshield and semi-automated surveys. For continuity, the same direction is collected every year.
- One lane driven in each direction for more than 3 lanes or a divided road
- The outside lane (also called lane #1) is driven when there is 3 or less lanes in the direction of travel, otherwise the second lane from the outside (lane #2) is driven

Because of the long life, its aging status, and high capital cost for concrete, there have been all lane surveys completed in 2004, 2009 and 2013. This allows WSDOT to make the most accurate decisions to manage it. Additionally, preservation strategies are becoming increasingly more lane-centric, not just on concrete. This cost efficient strategy is best done with increased data collection. It is therefore the recommendation of pavements to begin collecting data in all lanes on a regular cycle.

Data Collection: Distress Identification





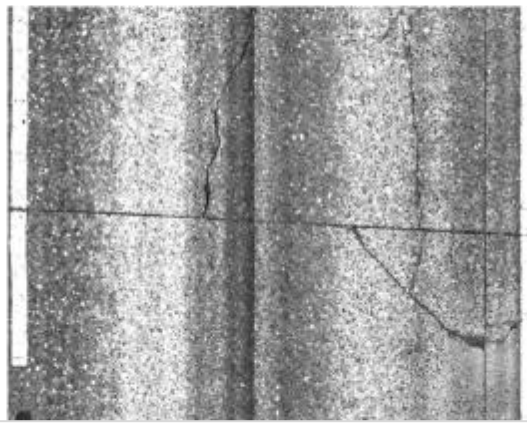
The second phase in data collection is the categorization of distresses from the pavement images. While roughness and rutting are important information about a roadway, the identification of distresses is the most important input into WSPMS because distress information is the basis for the site specific evaluation to find the most cost effective preservation alternative.

Since flexible and rigid pavements behave differently, they each have different distresses that are categorized. In addition to different types, many distresses have a low, medium and high severity associated with them. Detailed information can be found in the Pavement Surface Condition Rating Manual, which was published in 1992 in collaboration with WSDOT, the Northwest Pavement Management Systems Users Group and the University of Washington, and based off of existing practices refined since data collection began at WSDOT.

The consistency of distress identification is statistically verified for consistency and accuracy at three separate times for each annual set of pavement data collected. This quality assurance gives WSDOT a high degree of confidence in the distress identification process.

Equivalent Cracking

- Flexible pavement rehabilitation threshold of 10% high severity fatigue cracking
- Concrete rehabilitation threshold of 15% panels with multi-cracking
- Equivalent cracking models are well documented in The WSDOT Pavement Management System – A 1993 Update
- Model has proved valuable since 1993
- Model has been periodically reviewed, both internally and by the University of Washington



WSDOT categorizes several different types of surface distresses during the Distress Identification phase of Data Collection. In order to classify and predict pavement performance based on these distresses, the WSPMS converts all of these values into an equivalent amount of fatigue cracking for flexible pavements and multi-cracked panels for concrete pavement. The rehabilitation threshold is then based on this equivalency, and is 10% high severity fatigue cracking for flexible pavements and 15% multi-cracked panels for concrete pavement.

The factors used to calculate equivalency are well documented in The WSDOT Pavement Management System – A 1993 Update and is refinement from previous model used from 1969 to 1992. In addition to proving their use in the subsequent years, they have also been periodically reviewed internally and in conjunction with the University of Washington.

Rutting

- Rutting threshold of ½”
- From the WSDOT 2012 Survey:
  - 3.2% of WSDOT lane miles at or above ½”
  - 0.2% of WSDOT lane miles at or above ¾”
- Persistent issue due to studded tire wear
- Safety, structure and driver perception

Rutting is a surface depression in the wheel path. Rutting can be caused by issues in mix design, subgrade deformation after traffic loading, and studded tire wear. For WSDOT, the primary cause of rutting is studded tire wear, and was recently estimated by the Washington State Transportation Commission to cause $16 million worth of annual damage.

WSPMS uses a threshold of 0.5 inches before being considered for rehabilitation. While there is no definitive national threshold concerning rutting, as there is with IRI, the ½” is consistently used across many states. The 0.5” threshold is also more lenient than recommended in Improving FHWA’s Ability to Assess Highway Infrastructure Health. Moreover, a recent evaluation in the Journal of Transportation Engineering supported similar categorizations.

The primary justification for using rutting as a rehabilitation threshold is safety. Ruts filled with water can cause vehicle hydroplaning. Ruts can also be hazardous because ruts tend to pull a vehicle towards the rut path as it is steered across the rut.

Even though the primary justification to use rutting as a rehabilitation threshold is safety, it should not be considered similarly to other safety features, such as rumble strips. This is because rutting factors into public perception of roadway and is also a possible indicator of pavement structural issues.

International Roughness Index (IRI)

- Measurement of Pavement Roughness
- Rehabilitation Threshold of 220 in/mi
- As measured in 2012:
  - 2.8% of WSDOT roadways are at or above the 220 in/mi threshold
  - No asphalt or chip seal projects proposed in 13-15 biennium were above 220 in/mi average

IRI Categories of Roughness				
	WSDOT		FHWA	
	Threshold	% of WSDOT	Threshold	% of WSDOT
Good	<= 170	91%	<= 95	55%
Fair	171 – 220	6%	96 - 170	36%
Poor	> 220	3%	> 170	9%

IRI is an evaluation of smoothness of a pavement surface, which was developed by the World Bank in the 1980s. Specifically, the IRI is a model using the longitudinal profile of the road as an input and a mathematical formula to apply the response of a "quarter car" at a speed of 50 mph, the output being IRI. Higher values of IRI represent rougher pavements.

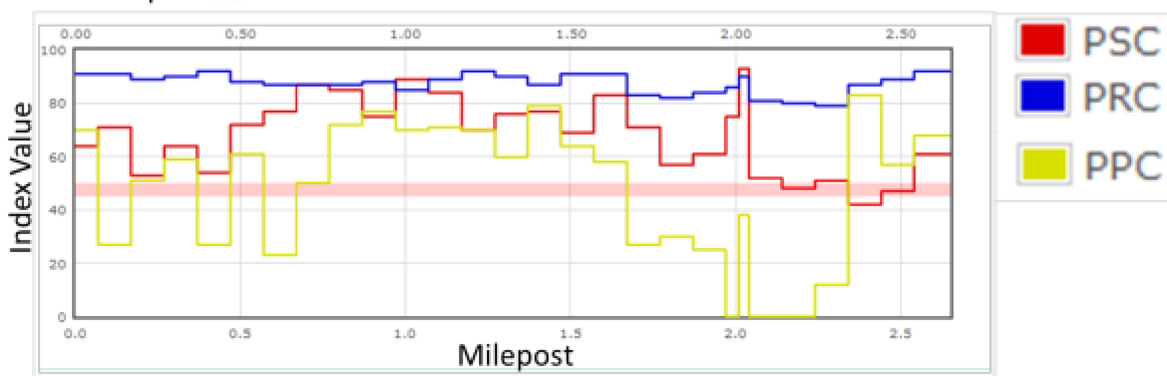
From the perspective of WSPMS, IRI is used as a measure of current condition and a trigger for resurfacing. The threshold for considering a pavement due for rehabilitation is 220 in/mi. However, because LLCC management of roadway is used at WSDOT, pavement is generally rehabilitated before IRI becomes an issue. From the 2012 condition survey, only 2.8% of lane miles were above 220 in/mi and there were 0 asphalt and chip seal projects proposed for the 13-15 with an average IRI at or above the 220 threshold.

IRI is also used at WSDOT for asphalt contract construction quality control and payment schedules. Sections being rehabilitated with an asphalt surfacing and that have IRI specifications are tested for IRI before and after the work is performed. Incentives are given for IRI lower than 60 in/mi and disincentives for IRI higher than 90 in/mi.

Nationally, IRI has been the key measure when reporting pavement condition and comparing between states. This is because IRI methodology has been well reviewed and the test is repeatable. The FHWA uses a threshold of 170 in/mi for differentiation between acceptable and unacceptable for Interstate roadways. From a national perspective, there is usefulness to reporting this information. However, there are also several known issues with the reporting and comparison of IRI information at a national level.

Pavement Indexes

- Normalizes defects from 0 (very poor) to 100 (very good) scale
- Thresholds reported are set at a score of 50
- Rehabilitation needed at 45-50
- PSC (Pavement Structural Condition)
  - Input: Equivalent Cracking
- PRC (Pavement Rutting Condition)
  - Input: Rutting
- PPC (Pavement Profile Condition)
  - Input: IRI



Pavement Indexes are used to convert the data collected from the condition surveys into meaningful information. There are two broad categories of pavement indexes; composite or individual. Composite takes into account multiple types of deficiencies. An example of a composite index is the generalized Pavement Condition Index (PCI) which may include rutting, roughness and cracking in its calculation.

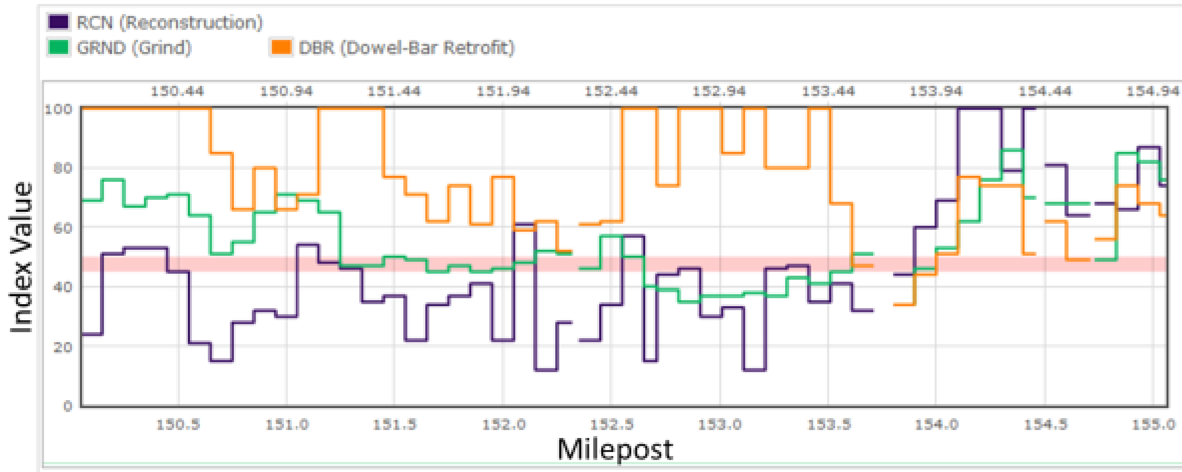
WSDOT uses individual indexes for pavement management which are scaled from 0 (very poor) to 100 (very good), with rehabilitation thresholds set at the index value of 50. The three main indexes used are:

- PSC (Pavement Structural Condition) – Assesses the structural health of the pavement based on cracking and patching present. The input is equivalent cracking and the model is a power function.
- PPC (Pavement Profile Condition) – Assesses the roughness of the road. The input is IRI and the model is linear.
- PRC (Pavement Rutting Condition) – Assesses the rutting of the road. The input is rutting and the model is linear.

Concrete Pavement Indexes

For concrete, the previous pavement indexes are further refined to indicate the type of rehabilitation needed

- RCN (Cracking) – Evaluates need for reconstruction
- GRND (Rutting and Roughness) – Evaluates need for diamond grinding
- DBR (Faulting) – Evaluates need for dowel bar retrofit



Due to the complex nature of concrete, additional indexes have been developed in 2009 and have been in use since. These additional indexes are:

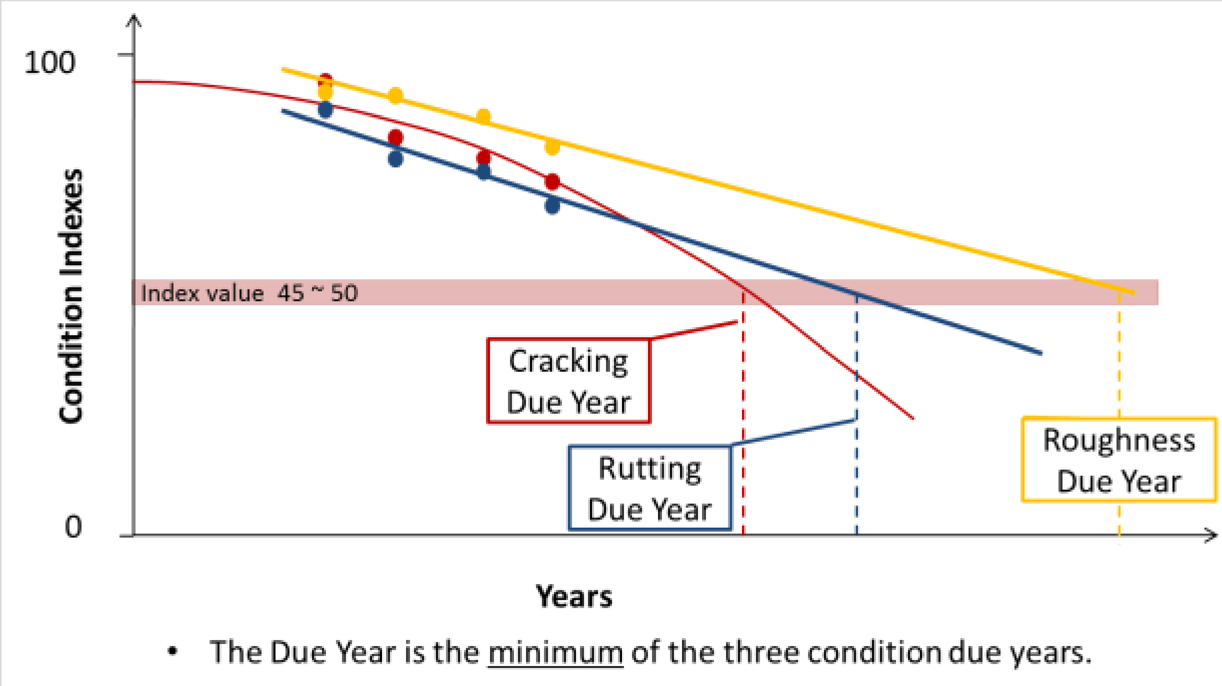
- RCN (Reconstruction) – Assesses the need to perform concrete reconstruction based on faulting and PSC
- GRND (Grinding) – Assesses the need to perform diamond grinding based on low faulting, IRI and rutting
- DBR (Dowel Bar Retrofit) – Assesses the need to perform dowel-bar retrofit, if none has yet been completed, based on faulting

Advantages to these indexes are that they have been developed in consideration to both historical data and in response to the all-lane concrete surveys in 2004 and 2009, and are based off of the actual corrective actions used in response to these surveys.

One type of distress not previously mentioned is faulting, which is a special type of roughness for concrete pavement. Specifically, it is the difference in elevation across the joints between concrete slabs.

An Example of Faulting

Performance Forecasting: Curve Fitting



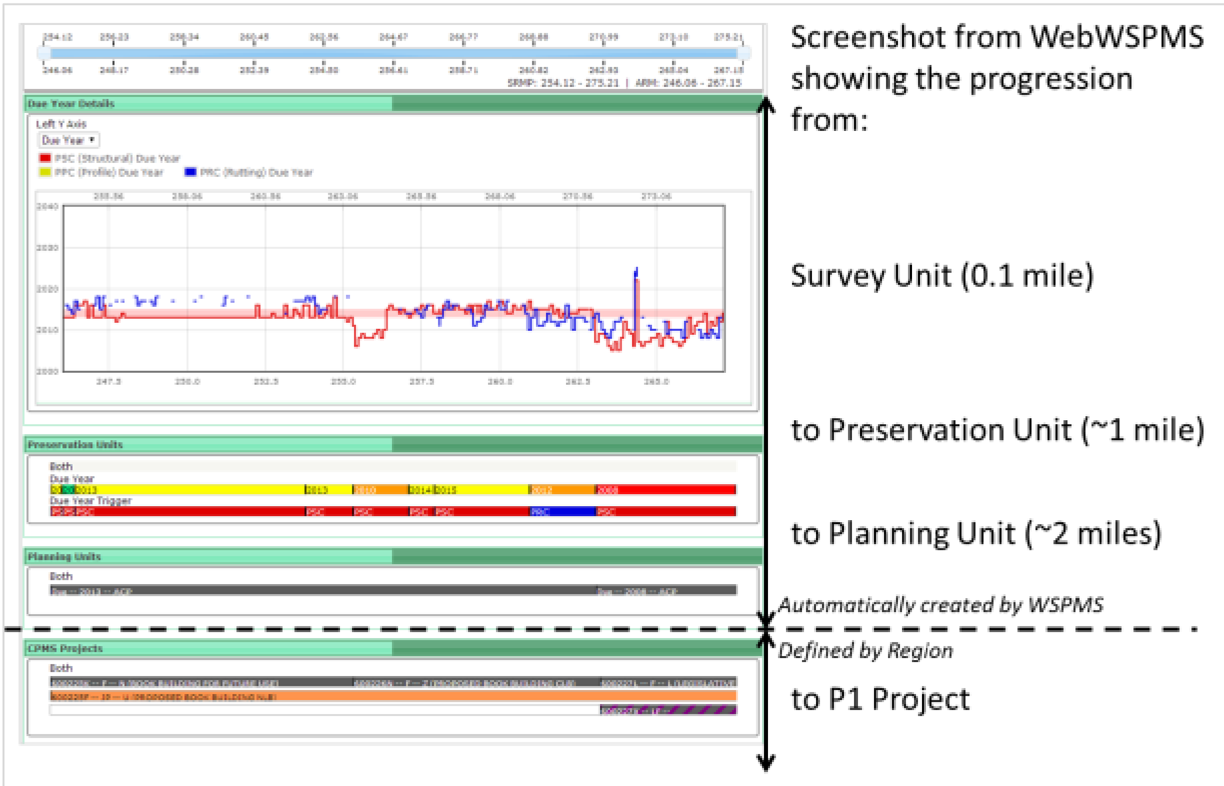
Historical Pavement Indexes are plotted and regression analysis is used to characterize and predict performance. This is referred to as curve fitting. Roughness and rutting follow a linear model while PSC uses a power model.

Regression analysis is performed using a seed (default) curve and the least squares algorithm. The default curves used are based on those documented in The WSDOT Pavement Management System – A 1993 Update. In terms of modeling terminology, WSDOT uses a deterministic prediction model reliant on family models (default) and site-specific (data based) information. Generally, pavement nearing the end of its service life has valid site-specific models, giving WSDOT a high degree of confidence that work being planned is necessary and cost effective. This confidence is greatly compromised when solely family models are relied upon.

A section is considered due for rehabilitation in the year that the index value reaches a value between 45 and 50. The Due Year assigned to a section is based off of the minimum year calculated from all indexes regressed.

The power model has been reviewed several times since originally documented in 1993, but because it has a long history of successful use it has not radically changed. Alternatives to the power model recommended include a logit model and a piecewise linear approximation, but have not been employed within WSPMS because of the significant effort that would be required to validate and implement these changes. However, due to the changing nature of preservation funding and increase in maintenance activity, the pavements branch recognizes that further refinements to the model can be a useful, albeit significant, investment.

Dynamic Segmentation



Another important characteristic of communicating pavement condition has to do with the length the information is applicable to. The WSPMS aggregates condition information at 3 separate levels to aid in decision making. The process of dividing up a network of routes into manageable segments is referred to as Dynamic Segmentation.

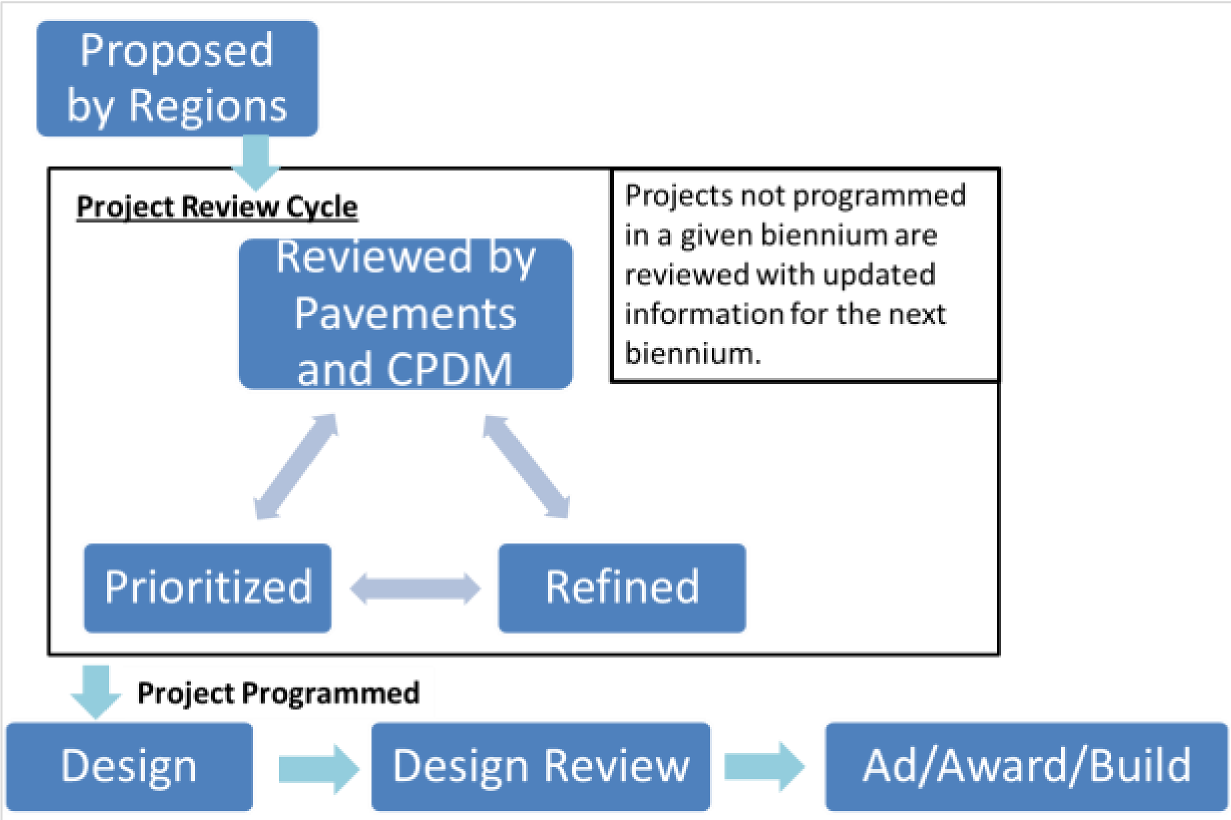
The smallest units are called Survey Units and are the "building block" within WSPMS. Survey Units have a target length of 0.1 mile and are homogenous for surface age, general surface type, basic roadway configuration (divided or undivided, more or less than 3 lanes total) and WSDOT region. Survey Units contain raw distress information (rutting, roughness, cracking, etc.), pavement indexes, and Due Years predicted for all pavement index types.

Preservation Units are aggregated from Survey Units based on similar condition. They are longer (average length of 1 mile), are the basis for overall Due Year information within the system, and are used chiefly to analyze the proper preservation activities.

Planning Units allow for a further generalization about Pavement Condition and are Preservation Units aggregated by similar Due Year. Planning Units average 2 miles in length and offer the fastest view for what is likely to occur at a Planning Level.

Having condition information readily available at 3 different scopes offers a powerful and flexible way to allow WSDOT engineers to maximize preservation cost effectiveness.

Preservation Project Flow



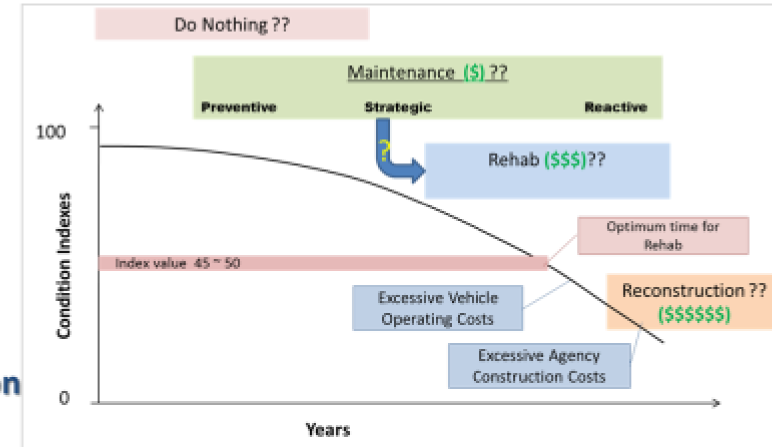
Historically, WSDOT preservation projects followed a linear progression from proposal to construction. Regional personnel used the WSPMS from odd years to identify needs and program projects for the upcoming biennium and the WSPMS from the following year to verify project priorities. For example, the 1997 WSPMS was used to develop the 1999-2001 biennium and the 1998 WSPMS was used to further verify the programmed projects.

The same general principle still applies. However, there has been a steady shift in the workflow from linear progression to an iterative process, which has its roots in changing from regional allocation to statewide prioritization in the 03-05 biennium. This shift was further progressed with decreased levels of preservation funding and the resultant need for more sophisticated prioritization in the last few biennia. This has also precipitated the need for having parametric estimates of needs up to 6 years out, meaning that the time from original input into CPMS until construction would mean an “incubation” period of 6 years. This extended time offers time for the optimal definition of preservation strategy and reaction to changing circumstances.

The current preservation project flow is shown above. It is built on strong communication between the regional personnel, the pavements branch and CPDM within the project review cycle. The WSPMS is used as the common framework for the iterative process from project proposal until it is constructed.

Project Review at Pavement Branch

- All preservation projects are reviewed at Pavement Branch for:
  - Right fix
    - Minimal design
    - Surgical approach
    - Value Engineering
  - Right time
    - Extend life with maintenance?
    - Effects of deferral?
- **Region – HQ Collaboration**



As indicated in the Preservation Project Flow, there are reviews that function as checks and balances during the project planning phase. On the surface this may seem redundant. However, this process has evolved (and is continuously being refined) based on WSDOT's long history and experience with program and pavement management. Moreover, this review cycle supports best practices in asset management, as supported by the AASHTO Transportation Asset Management Guide (January 2011):

"Opportunities for life-cycle cost reduction are typically greatest in the **planning stage**, where approximately three quarters of factors affecting life-cycle costs are decided." (Emphasis added)

Therefore, all pavement preservation projects are reviewed at the pavements branch to ensure that the project is the right fix at the right time. This includes checking the project follows value engineering, minimal design, takes into consideration "surgical approaches" (lane specific work) and has taken advantage of life extension through maintenance. It also is analyzed from a perspective of the risks involved if the project needs to be deferred. Overall, this process requires strong collaboration between Region and Headquarters personnel, to ensure that questions are properly addressed and agreed refinements to projects are made.

Project Prioritization

Prioritization: Categories

- First step in prioritization was to create categories (lower number has higher priority)
  - Category 1 refers to projects already programmed
  - Category 2 is for projects where high risk of major expense is identified
  - Category 4 is for asphalt to BST conversions (previous asphalt with new BST surface).
  - Category 5 is general category for all projects with no special considerations.
  - Category 6 is for projects that can be deferred with maintenance.
  - Category 8 is for projects that are mostly ramps.

Prioritization: Ranking Factor

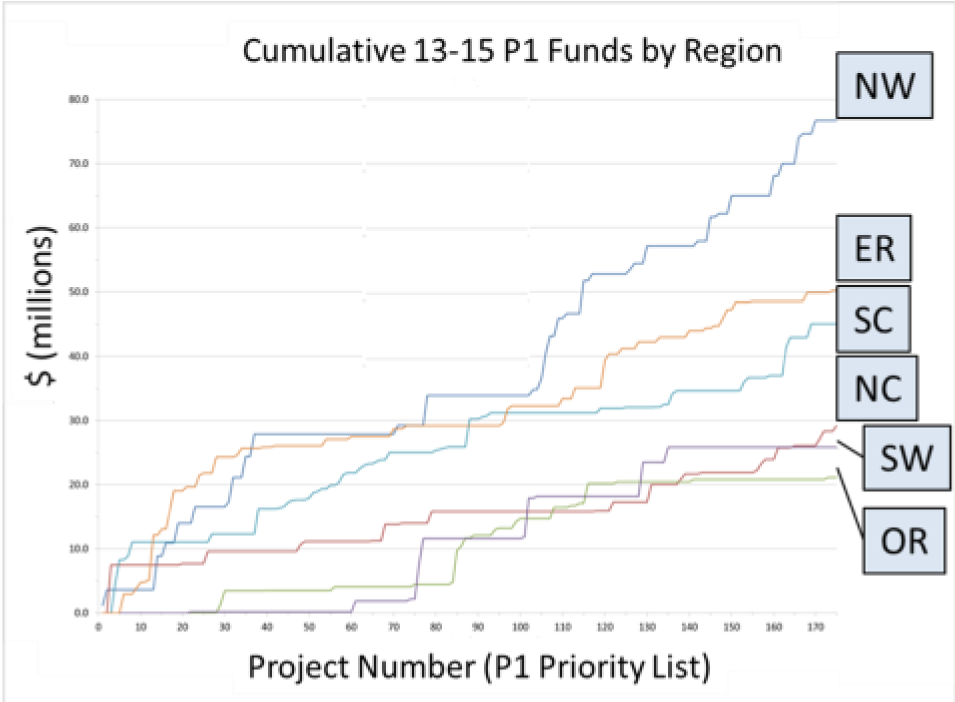
- Second step in prioritization was to calculate ranking factors based on:
  - Cost
    - $ per lane-mile (total CPMS cost)

    For all other factors being equal, a higher cost per lane-mile will reduce the priority.
  - Lane-mile years gained
    - (lane-miles multiplied by number of years of life gained by project).

    For all other factors being equal, a lower value of lane-mile years gained will reduce the priority.
  - Number of trucks per year
    - The higher number of trucks per year indicates higher potential for rapid deterioration, and importance to commerce.

    For all other factors being equal, a lower number of trucks per year will reduce the priority.

- 13-15 prioritization resulted in funding to regions roughly proportional to the pavement backlog in each region.



A natural outgrowth of the proposal and review of preservation activities is to prioritize them. At WSDOT, the ultimate decision about the funding of a preservation project is made by CPDM and the legislators. The role of pavement management and the WSPMS to provide prioritization guidance to these entities has evolved over the years.

It can be said that prioritization has existed within WSDOT since data collection started in 1969. In pavement management, there are two primary prioritization strategies that have historical significance; a) Worst First and b) Lowest Life Cycle Cost.

RCW 47.05 was interpreted as a worst first prioritization up until its change in 1993. This meant that the sections with the lowest pavement condition score were put at the highest priority. During the 1980s analysis of the WSPMS information concluded that a Lowest Life Cycle Cost strategy was more effective than a Worst First strategy. In this strategy, the optimization of the network condition at the lowest cost was more cost effective than worst first. This was also confirmed in the Priority and Programming Study completed in 1992 and spurred the inclusion of lowest life cycle cost into the RCW 47.05 update in 1993.

The Pavement Management prioritization strategy changed to “Due” before “Past Due” in prioritization. WSDOT was able to improve overall network conditions drastically through this implementation. However, the continual reduction in sufficient preservation funding has created a need for more sophisticated prioritization. In other words, what happens when two projects are considered the LLCC for different roadway segments, but there is only funding enough for one?

The need for a more sophisticated prioritization had escalated at the same time ARRA funding was introduced in the 09-11 biennium. This is when a prioritization scheme was first developed within Pavement Management and implemented in collaboration with personnel from CPDM. This methodology was refined further for the 13-15 biennium, the culmination of which is explained further.

Close to 300 flexible pavement projects were analyzed and prioritized for the 13-15 biennium. The prioritization of these projects followed 3 steps:

1) Project Categorization
2) Calculation of the Ranking Factor called Dollars per Lane Mile Truck ($/LMT)
3) Sort (rank) based on category and Ranking Factor

The first step was to place projects into the following categories (lower number has highest priority)

- Category 1 - Projects already programmed
- Category 2 - Projects where high risk of major expense is identified. If rehabilitation is delayed too long, then the risk of reconstruction, which is 2 to 5 times the cost of rehabilitation
- Category 4 - Asphalt to Chip Seal Conversion (asphalt with a new chip seal surface). This has a higher priority because life cycle costs of chip seal is one-third the cost of asphalt
- Category 5 - General category (no special considerations)
- Category 6 - Projects that can be deferred with maintenance
- Category 8 - Ramps

The second step is to calculate a ranking factor based on:

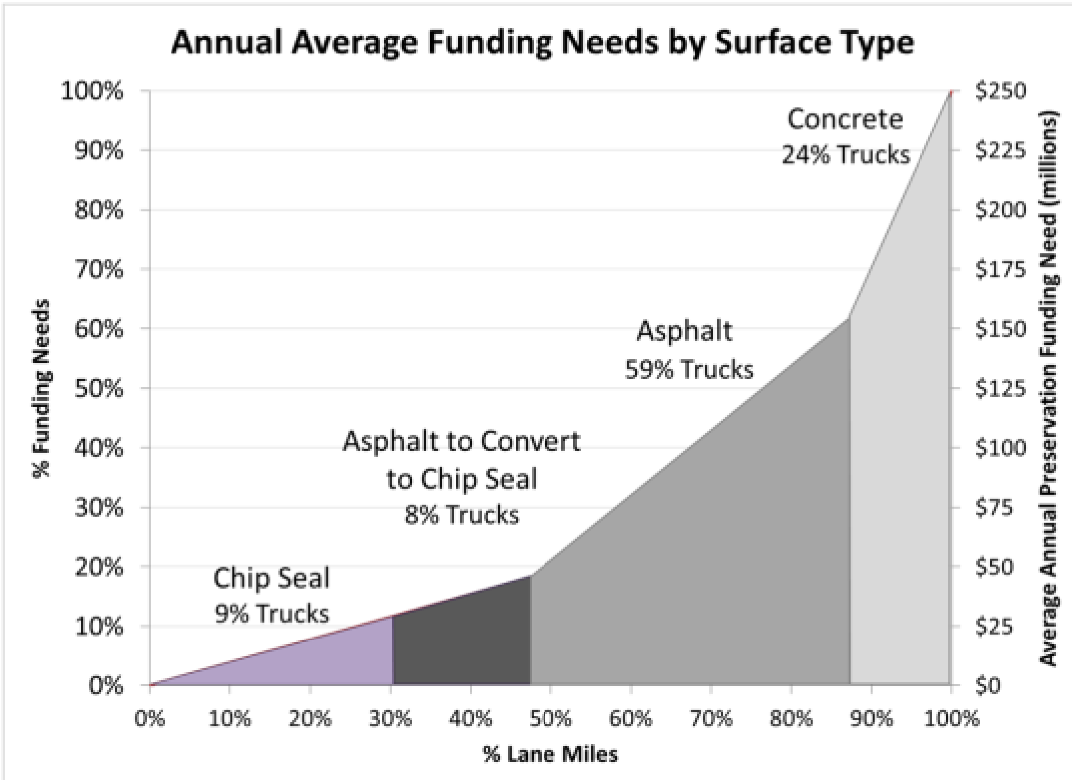
- Cost: The dollars per lane mile construction cost including PE and traffic control, divided by the total lane miles paved. <u>For all other factors being equal, a higher cost per lane-mile will reduce priority.</u>
- Lane-Mile Years (LMY) Gained: The lane miles paved multiplied by the expected years of life gained by the project. <u>For all other factors being equal, a lower value of lane-mile years gained will reduce priority.</u>
- Annual Number of Trucks: The higher number of trucks per year indicates an importance to commerce and a higher potential for rapid deterioration. <u>For all other factors being equal, a lower number of trucks per year will reduce the priority</u>.

These factors are combined into a single term called Dollars per Lane Mile Truck ($/LMT)

Projects were sorted by category then $/LMT, and a ranking was assigned based on the order. A final list was completed in August 2012 and used for statewide prioritization. This prioritization process was explained in the internal document, ACP and BST Priorities, and distributed to WSDOT regions for communication and review. An analysis of the projects before and after prioritization showed a significant decrease in backlog miles saving WSDOT $80 million. This prioritization has been further validated by the WSPMS Forecaster and was similarly used to prioritize the 15-17 biennium and is being used to prioritize the 17-19 biennium.

Network Tiers

Can preservation funding be stretched by prioritizing to targeted portions of the network?



A logical extension of pavement prioritization is to group existing roadways by certain characteristics and then prioritize groups when allocating preservation funding. Examples of existing groups are:

- NHS vs. non-NHS
- FGTS (T1, T2…) freight corridors
- Highways of Statewide Significance
- Concrete vs. Asphalt vs. Chip Seal

Can preservation funding be stretched by prioritizing to targeted portions of the network?

Analyses using both the current distribution of the network and the WSPMS Forecaster showed that prioritizing by specific sub-networks did <u>not</u> result in a more optimum allocation of funds, based on several performance measures. The results showed:

- There is no simple rule for prioritization.
- Funding requirements follow the traffic. High truck corridors have high preservation costs.

- Looking at the graphic above, eliminating the bottom 50% of the lane miles only reduces network funding needs by 20%

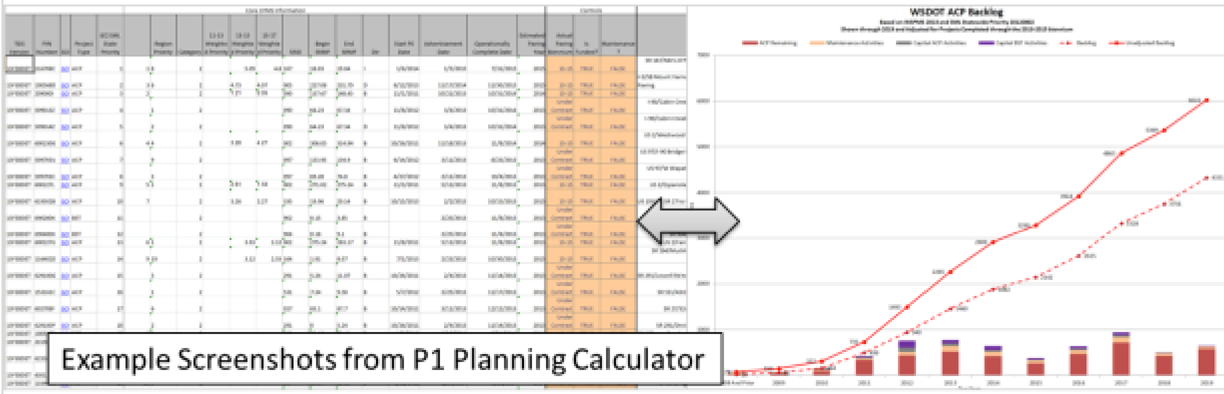
Using the current method of prioritization (analysis of individual project performance measures and aggregating them over the network) results in the most optimal allocation of planned funding.

However, this strategy is based off of the fundamental assumption that preservation funding will be increased in the immediate years and approach lowest life cycle levels within the next ten. Connecting Washington is expected to adequately meet this assumption, at least for the next six to ten years. Without Connecting Washington, it would have been time to strategically choose which roadways to fully support in the lowest life cycle cost network. The other roadways would have been subjected to higher vehicle operating costs and freight damage, lower safety and possibly lower speed limits, and an increased cost if funding allows the restoration of its roadway. At the previously planned sustained 40% funding, it would only be feasible for WSDOT to support the Interstate roadways (20% of the lane miles), leaving the other 80% less safe, less reliable and less cost efficient.

Network Level Decision Making

Preservation Program Review at Pavements Branch

- Further review of the preservation program is accomplished using the *P1 Planning Calculator*
  - What is the effect of the program on the backlog?
  - What are the effects of securing additional funding?

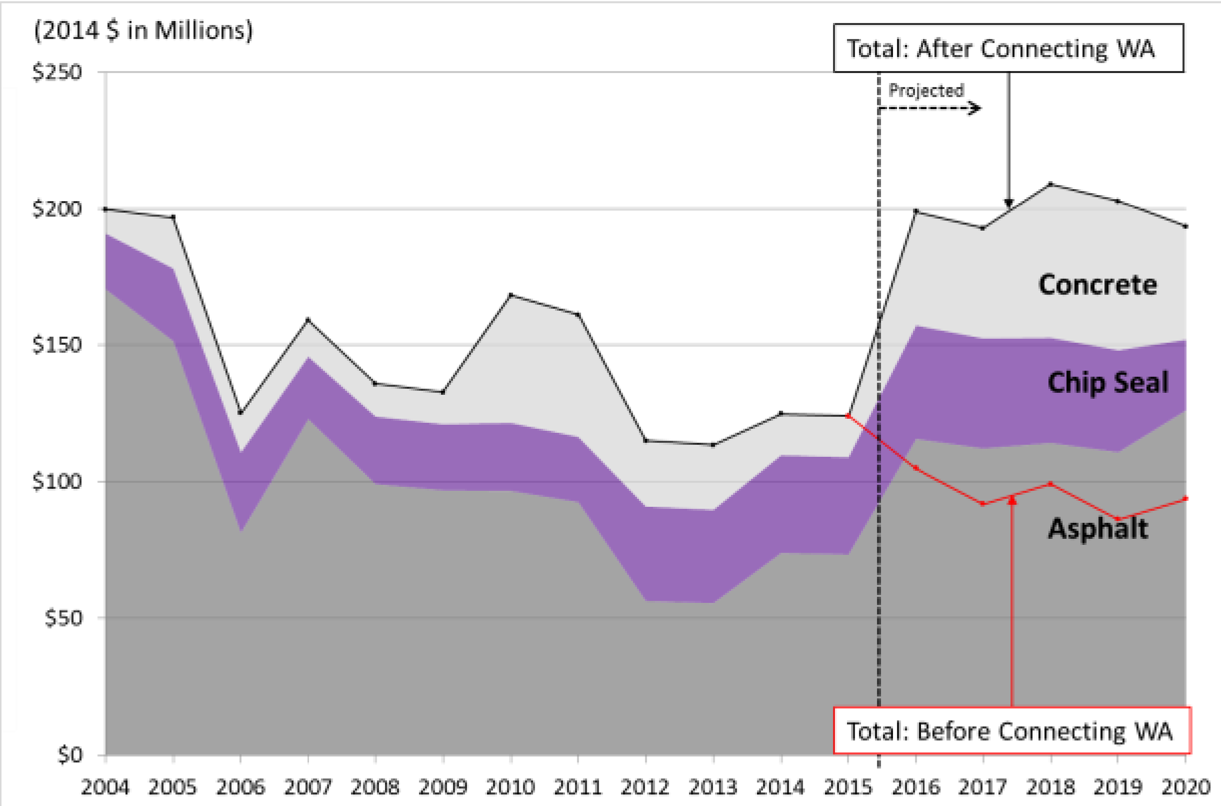


Example Screenshots from P1 Planning Calculator

Pavement Management also validates the proposal and prioritization of the P1 projects from the network perspective. An example of the project proposal perspective is checking the "coverage" of Due and Past Due miles by funded and/or proposed P1 projects. This ensures that statewide needs are being properly identified during the P1 Project workflow.

The P1 Planning Calculator is a Microsoft Excel spreadsheet populated with P1 Project data analyzed by WSPMS. The spreadsheet allows the user to alter project approval scenarios and see the overall effects on the preservation backlog, funding levels and project types from a statewide and regional perspective.

Preservation Funding



The decline in pavement preservation funding over the last decade has been significant. In the 1990s, WSDOT averaged $234 million per year in pavement preservation funding. This has since declined, and before Connecting Washington planned funding levels were at $101 million per year over the next 8 years. Connecting Washington allows WSDOT to restore much of the needed preservation funding.

WSDOT has been able to keep its pavement roadways in a good state of repair over the last decade of funding decline through several innovations in pavement asset management. This includes:

- Taking advantage of the long life of its concrete roadways
- Using up the buffer of asphalt service life built up in the 1990s
- Starting an aggressive program to use chip seal surfacing where appropriate
- Starting an aggressive program to use maintenance to gain valuable years of surface life
- Implementing new construction practices to extend cost efficiency, including in place recycling and crack and seat overlays

While the innovations realized during this funding decline have helped refine pavement asset management at WSDOT, they would not have been able to sustain the levels of underfunding planned prior to Connecting Washington.

Simplified Forecasting

Simple estimate of Chip Seal Need:

$$\frac{7{,}000\ applicable\ lane\ miles}{7\ year\ average\ life}\ x\ \$40{,}000\ per\ lane\ mile = \$40\ M\ annual\ need$$

Apply simple estimates over a range of assumptions:

	Asphalt	Chip Seal	Concrete
Avg. Life	15-17 Years	7-8 Years	40-60 Years
Avg. Cost per Lane Mile	\$200,000 – 250,000	\$35,000 – 50,000	\$2,000,000 – \$3,000,000
Applicable Miles*	9,000	7,000	2,000
Avg. Annual Cost	\$115 M – \$130 M	\$35 – \$45 M	\$75 M – \$100 M
Total Annual Cost: \$225 M – \$275 M			

**This is not the current distribution of lane miles by surface type. The values are rounded for the simplified calculation. Additionally, asphalt lane miles likely to be resurfaced with a chip seal are put in the chip seal category.*

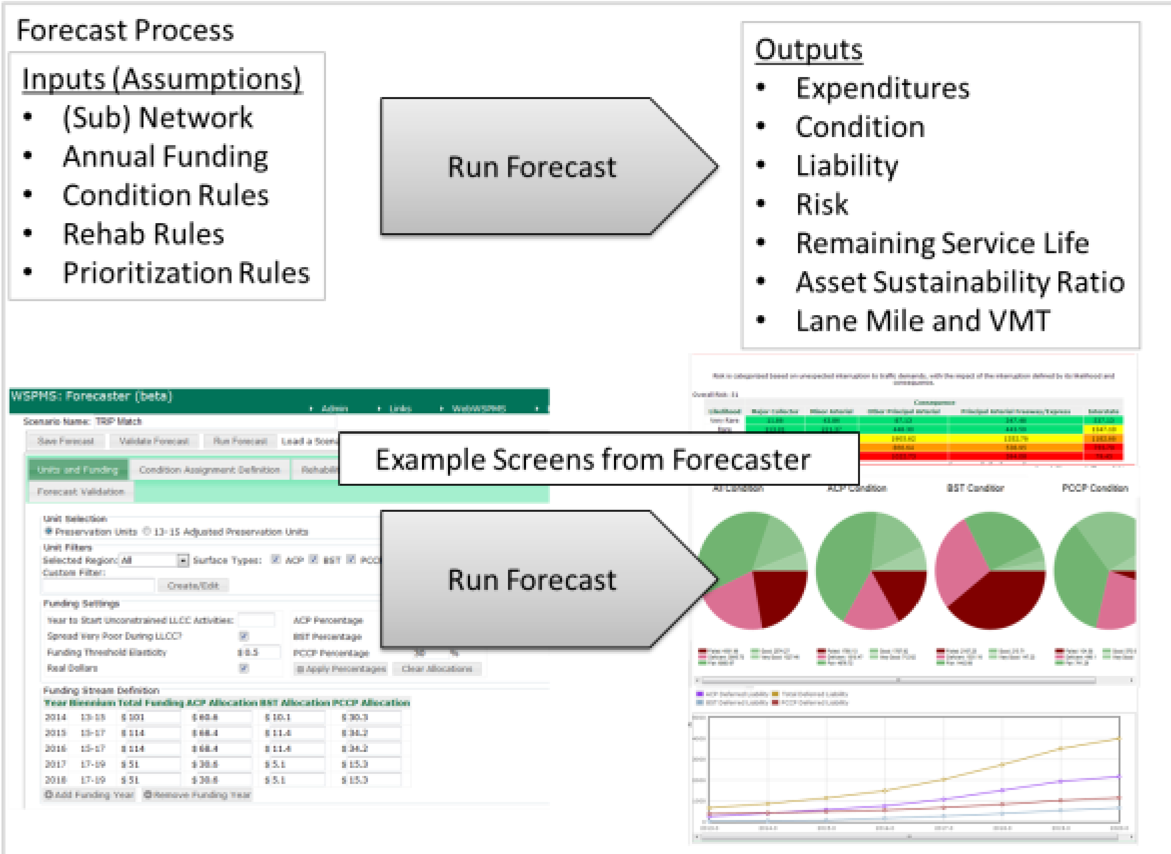
***Estimation based on assumptions of average life, cost and applicable lane miles.*

Determining preservation need is a fundamental aspect of Pavement Management. A quick and straightforward estimate of annual average need can be made with a few fundamental averages over the pavement network. These are the average life, or time between major activities, the average cost of these major activities and the miles the activity is applicable to. A simple estimate for chip seal need is shown above.

However, this type of simple estimation must be applied over a range of assumptions to get a good window for preservation need. This can be conceptualized in the three major surface types of asphalt, chip seal and concrete. The diagram above estimates a range for WSDOT between \$225 M and \$275 M of annual preservation need.

In 2010, WSDOT was asked by the Legislature as part of SB 6381 to provide a 10 year summary of preservation needs at planned funding levels, to keep the backlog steady and to eliminate the backlog. This is in the document WSDOT Strategies Regarding Preservation of the State Road Network. Detailed information about the assumptions and methodology used are explained in the document. Based on the assumptions made within the document, Preservation Need was estimated to be \$2 billion over 10 years for flexible pavement and \$900 million over 10 years for concrete pavement.

WSPMS Forecaster



In addition to estimation of need, Pavement Management benefits from illustrating the impact of different strategies, or "What If" analyses. What if questions may include:

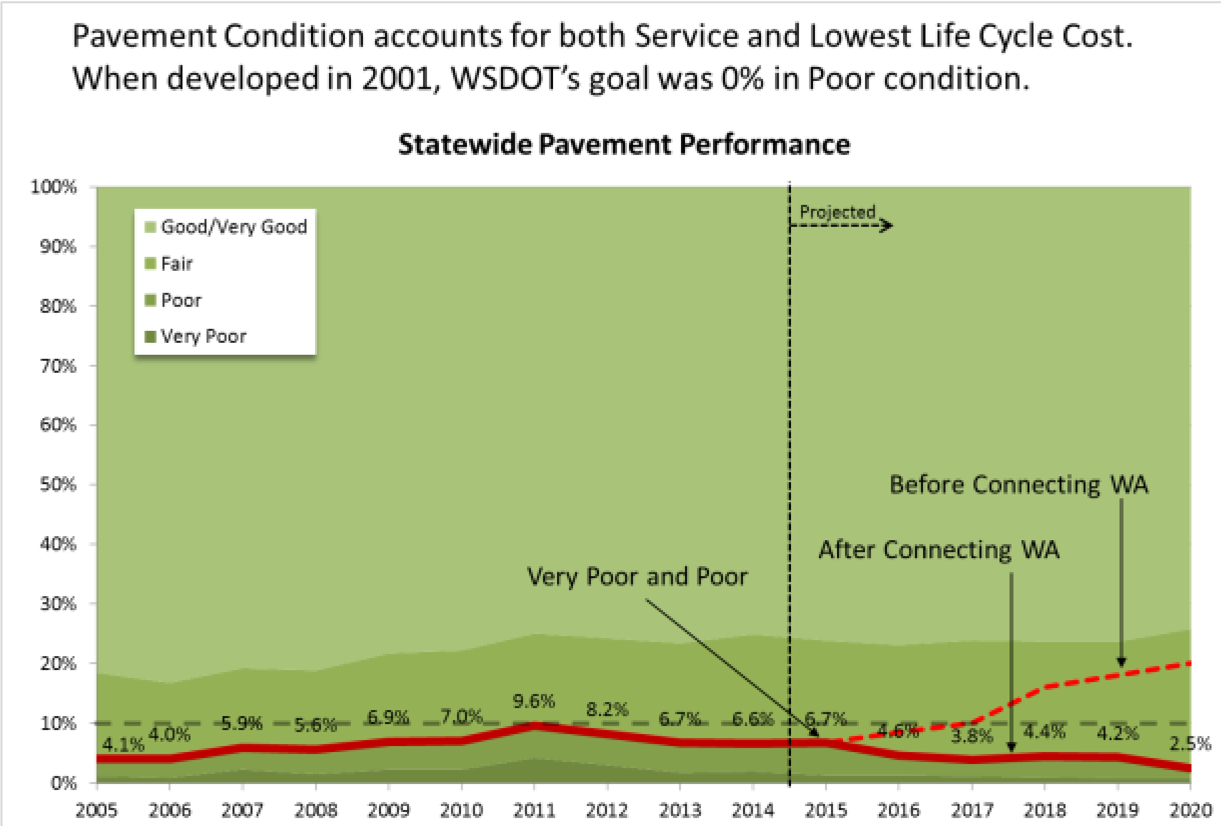
- What if we had 50%, 75% or 100% of needed funding?
- What if we prioritized Interstate before Principal Arterial?
- What if we fully funded chip seal needs before funding other needs?

Often, these questions are not asked singularly. Questions such as, "What if we had 50% funding, fully funded chip seals and the prioritized by Functional Class?" may be asked.

A Forecasting tool was recently added to WSPMS and is still in development. It can be classified as being in beta, as it is continually refined as it processes more "What If" types of analyses. Explanation of the Forecaster is in Modeling and Analyzing Pavement Preservation Strategies and documentation on its use is in the WSPMS User Manual.

Early results from the WSPMS Forecaster were analyzed in conjunction with engineering judgment and existing manual forecasts, and then used in communication about predicted performance measures (such as in GNB #48, #52 and #56). The Forecaster was also used to analyze several different prioritization strategies and validate the prioritization strategy currently used (categorize then rank by $/LMT).

Performance Measures: Pavement Condition



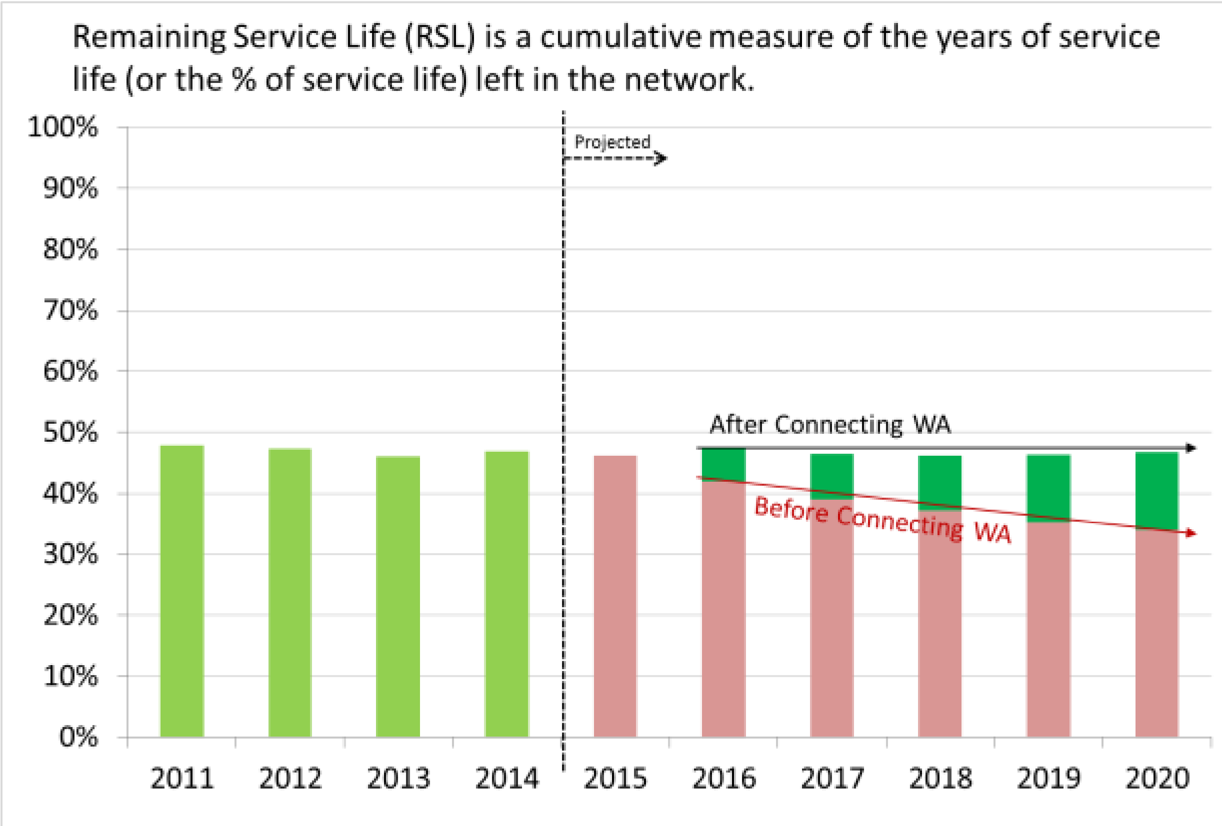
From a historical perspective, condition has been the single performance measure reported for concerning Pavement Assets. While there are five categories (Very Good, Good, Fair, Poor and Very Poor), traditionally the division between Good (Fair, Good and Very Good) and Poor (Poor and Very Poor) has been focused on.

It is also important to understand the methodology for producing the condition percentages. Specifically, the percentages reported have the following characteristics:

- Condition definitions are based off the minimum value between roughness, rutting and PSC
- Condition levels are based off of rehabilitation thresholds, not strictly by public perception
- Condition information is assigned to Survey Units (0.1 mile segments)
- Only include information from year being reported
- Exclude sections under construction

There are several nuances to this type of reporting that are often scrutinized. First, most people associate condition with public perception of the roadway and not the effective management of the asset, which is what the categorizations are based off of. Second, it does not account for future need. There are several different scenarios that can have the same current condition with varying amounts of immediate need. Third, condition is a lagging indicator. As WSDOT has experienced, it may take several years of funding shortfall to effectively move the overall network condition to unacceptable levels.

Performance Measures: Remaining Service Life



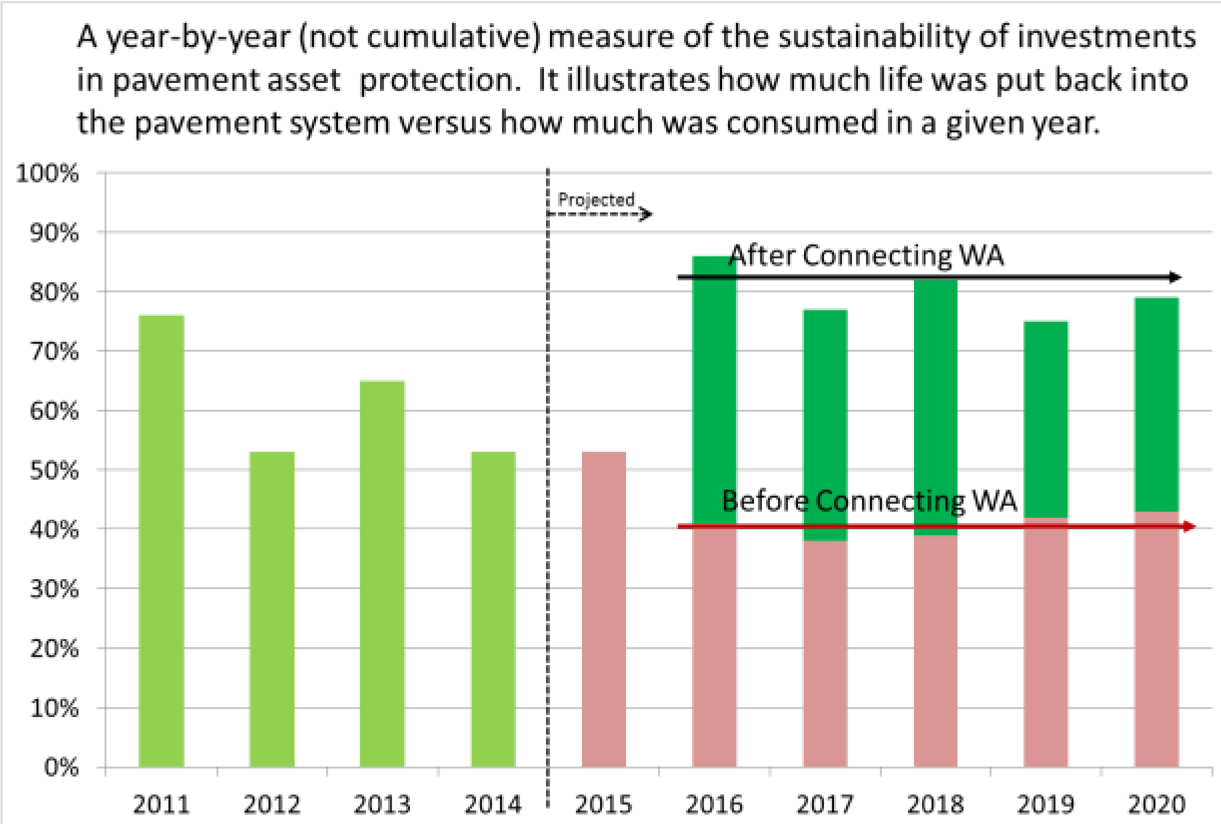
Starting in the Gray Notebook #48, 3 other performance measures were introduced to aid in communication between Lowest Life Cycle Costs, condition, and impending need. Remaining Service Life (RSL) is the first of these performance measures.

Remaining Service Life (RSL) is a cumulative measure of the years of service life left in the network. RSL has the following characteristics:

- Measures the average pavement life, defined as number of years until due, expressed as a percentage of typical pavement life
- A healthy system has an RSL between 45% and 55%
- An ideal system would have an RSL of 50%

There has been a net 10% loss in service life (from ~58% to ~48%, which is an 18% drop in Remaining Service Life), for asphalt from 2003 through 2013. Prior to Connecting Washington, a drastic drop in Remaining Service Life was predicted. After Connecting Washington, Remaining Service Life is expected to remain fairly steady but not necessarily increase. This is mainly because the concrete network is going to continue to age and the major reconstruction necessary for the I-5 corridor is expected to be delayed with triage until 2020 to 2030.

Performance Measures: Asset Sustainability Ratio

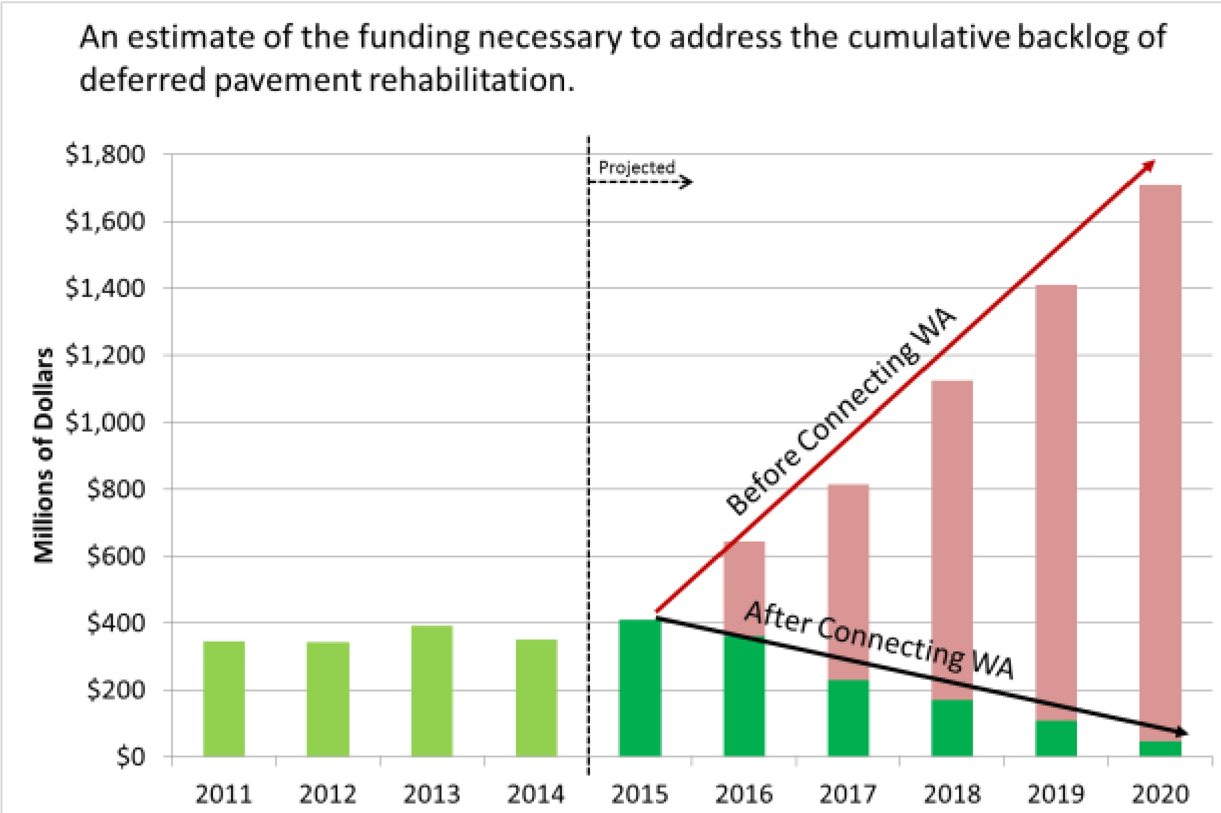


The Asset Sustainability Ratio measures the annual sustainability of investments in pavement asset protection. For a single year it:

- Measures how well WSDOT's pavement replenishment is keeping up with pavement wear
- Annual consumption for WSDOT pavements is ~18,000 lane-mile years and ~29.5 billion VMT (for lane mile and VMT weighting, respectively)
- Annual replenishment is calculated as a summation of average life added per rehabilitation activity performed.
- WSDOT goal is 0.9

The long term effects of the Asset Sustainability Ratio are evident in the Remaining Service Life.

Performance Measures: Deferred Preservation Liability



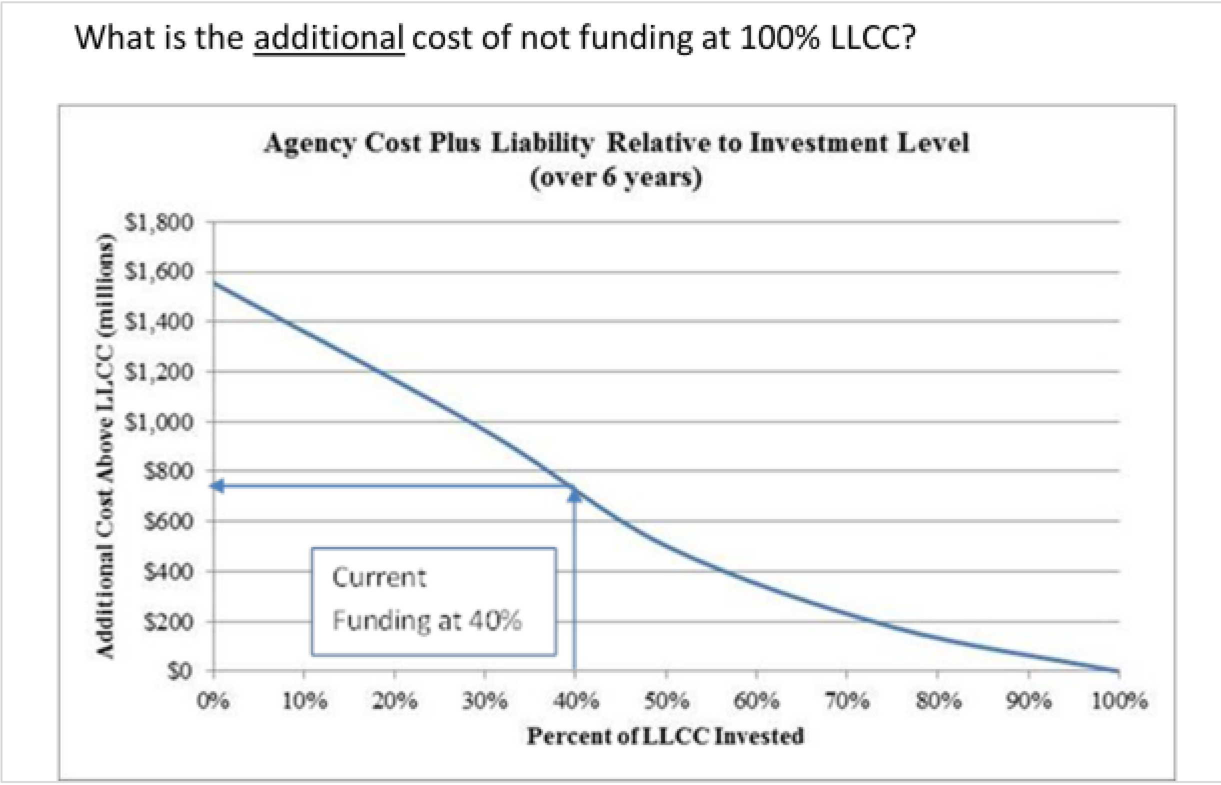
The Deferred Preservation Liability is an estimate of the funding necessary to address the cumulative backlog of deferred pavement rehabilitation. The estimate takes into consideration the higher cost to properly rehabilitate roadways as pavement condition gets worse and needs more extensive repair.

The Deferred Preservation Liability is susceptible to several assumptions. For reporting the existing Deferred Preservation Liability in the Gray Notebook, exact numbers reported are based on a) the distribution of Preservation Unit Due Years, b) the average resurfacing costs for asphalt and chip seal, c) the average triage cost of concrete (diamond grinding and dowel bar retrofit) d) the average cost of concrete reconstruction and e)The Due Year used to start accumulating a liability, which is currently 2 years before the year being reported (only Preservation Units due in 2010 and prior were accumulated for the 2012 number reported). Moreover, because WSDOT does not currently have an issue with flexible pavement reconstruction and aggressive strategic maintenance has been used, there were no penalties yet assessed for flexible pavements (i.e. no additional rehabilitation or reconstruction penalties).

Assumptions are further compounded when estimating future liability, which must also take into account a predicted funding level, a predicted strategy for spending that funding level, predicted pavement performance which corresponds to predicted liability.

WSDOT’s goal is to have a Deferred Preservation Liability of $0.

Cost of Inadequate Funding



An alternative way to think about the liability is to account for the additional costs achieved at lowest life cycle. The graph above conceptualizes the amount of liability based on levels of funding relative to what is considered Lowest Life Cycle Cost (LLCC) funding. At the 40% funding level, which was planned prior to Connecting Washington, a liability of approximately $750 million is accrued over 6 years. As the length of underfunding extends, liability will increase exponentially as the significant investment Washington has made in its pavement structures is sacrificed. By restoring much of the needed funding in pavement preservation, Connecting Washington helps to avoid much of this liability.