We will be discussing preventive maintenance techniques for both AC-surfaced pavements (including asphalt overlays of concrete pavements) and PCC-surfaced pavements. Listed here are the preventive maintenance techniques for AC pavements that we will be discussing.

Note that many of these treatments are also rehabilitation treatments, but we will be discussing them as potential preventive maintenance treatments.

For mostly linear cracking in AC pavements, two different crack treatments are available. Crack filling is a lower level operation in which lower quality sealant materials are used and little, if any, crack preparation is performed. It is applicable for non-working cracks only, that is, those cracks that do not experience significant horizontal movements (less than 2 mm). Because crack filling is more of a “stop gap” procedure, it is not really recommended as a preventive maintenance treatment.

Crack sealing, on the other hand, is a more intensive operation in which the crack is carefully prepared (routing, cleaning, drying, backer rod insertion) and a high quality sealant material is placed. Crack sealing is geared at working cracks in the pavement.

There are a series of surface treatments that are commonly used on asphalt pavements. We will now look at each of these briefly.
Fog seals are a light application of a diluted asphalt emulsion (typically 8:1 or 9:1 mixture) placed primarily to seal the pavement and prevent raveling. The pavement must be in relatively good condition, without cracking or major raveling. Slow-setting emulsions are most commonly used for fog seals, and these take time to break, so the pavement must be closed to traffic for about 2 hours after placement. Because fog seals have the potential for reduced surface friction if excess asphalt is inadvertently applied to the pavement, they are not recommended on high-speed roadways.

Again, fog seals are most effective on pavements in good condition. The performance life of a fog seal is about 1 to 2 years, and repeated applications are expected to provide improved effectiveness. However, no formal studies have been conducted to evaluate the effect of fog seals on prolonging pavement life.

Slurry seals are a mixture of well-graded aggregate and a slow setting asphalt emulsion. They are appropriate for use when the primary deterioration is related to excessive oxidation and hardening of the existing asphalt. Aggregates must be clean, angular, durable, well-graded, and uniform (prefer 100% crushed). A mix design should be performed to ensure that the desired properties and break times are achieved.

Photo of the placement of a slurry seal. The emulsion is brown in color until it breaks.
Slurry seals typically provide between 3 and 5 years of service on roads with moderate to heavy traffic. No information on the increase in pavement service life is available.

Under the SHRP program, various maintenance treatments are being evaluated. These SPS-3 study results are based on a 5-year evaluation.

Microsurfacing is similar to a slurry seal but it uses a polymer-modified binder and higher quality aggregates. This technique addresses oxidation and raveling on the pavement surface. However, it can also be used to fill wheel ruts up to 40 mm (1.5 in) deep in a single pass. There are two generally accepted aggregate gradations; the choice depends on the type of application. Microsurfacing has been used successfully on both low- and high-volume roadways.

The use of a CSS-1hp binder is common (the “CSS” indicates a cationic, slow setting emulsion, the “1” its relative viscosity [a “-2” is more viscous than a “-1”], the “h” meaning a harder grade of base asphalt was used in the production of the emulsion, and the “p” meaning polymer-modified).

Microsurfacing has been found to perform well for 4 to 7 years, depending on the condition of the existing pavement. Ruts up to 50 mm (2 in) have been successfully filled, with recurrence of rutting within 3 to 5 years. Initial friction numbers range from the mid 40s to upper 50s, where higher friction numbers represent greater friction (highway agencies typically require improved surface friction when the values dip below about 35). When underlying cracks are not working, microsurfacing delays the development of those cracks in the new surface.

Microsurfacing has been successfully used on both low and high volume roadways. No information is available regarding the extension to pavement service life provided by microsurfacing.

Chip seals, also referred to by other names including surface treatments, bituminous surface treatments, surface dressings, and seal coats, are an application of asphalt (commonly asphalt emulsion) directly on the pavement followed by an application of aggregate chips. The resulting treatment is then rolled to embed the chips in the binder.

Chip seals are effective in sealing the pavement and improving surface friction. Although they historically are used on low volume roadways, many agencies have been experimenting with them on higher volume roadways; e.g., Washington State has used chip seals on pavements with 80,000 ADT.
There is a complete family of treatments that falls into the “chip seal” category. Rubberized asphalt chip seals are commonly used in conjunction with overlays to retard reflection cracking. Sand seals are used to enrich a dry, oxidized surface and to prevent the intrusion of moisture and air. Sandwich seals consist of large aggregate, spray of asphalt emulsion, and application of smaller aggregate; they are used to seal surface and improve skid resistance. Cape seals are a chip seal covered with a slurry seal and are used to provide a dense waterproof surface with improved skid resistance.

Asphalt emulsion or asphalt cement may be used as the binder, with asphalt emulsions being more commonly used. The aggregate should be as close to one size as possible. Pneumatic rollers are preferred because the adequately embed the aggregate without crushing or fracturing it. Multiple chip seals may add up to 25 mm (1 in) of structure to the existing pavement. Traffic may be allowed on the chip seal after rolling is completed; however, speed should be limited to 32 km/hr (20 mi/hr) for 2 hours after placement.

Performance of chip seals is variable and dependent upon the proper application of the asphalt binder and aggregate chips and the subsequent compaction. Better performance can be found in non-freeze climates. Other factors include contractor experience and project selection. Any others?

Texas reports an average life of 6 to 7 years; New York reports that chips seals with an asphalt emulsion have lasted 3 to 4 years; Washington reports that chip seals with a polymer-modified sealer have lasted 5 to 7 years under heavy traffic. Multiple chip seals can provide up to 10 years of service.
Here is a summary of costs for some of the surface treatments that have been discussed. Each agency must determine which treatments are the most cost effective for their particular applications.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Life, years</th>
<th>Cost, $/m² ($/yd²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fog seal</td>
<td>1 - 2</td>
<td>0.24 - 0.30 (0.20 - 0.25)</td>
</tr>
<tr>
<td>Slurry seal</td>
<td>3 - 5</td>
<td>0.84 - 1.14 (0.70 - 0.95)</td>
</tr>
<tr>
<td>Chip seal</td>
<td>4 - 7</td>
<td>0.96 - 1.32 (0.80 - 1.10)</td>
</tr>
<tr>
<td>Microsurfacing</td>
<td>4 - 7</td>
<td>1.50 - 2.40 (1.25 - 2.00)</td>
</tr>
</tbody>
</table>

Descriptions of several preventive maintenance recycling treatments follow, specifically cold in-place recycling and hot in-place recycling.

What are these treatments? How do they differ? How can they be applied in the preventive maintenance setting? What experience do you have with them?

CIR mills off a portion of an existing AC pavement and reuses that milled material back as a layer on the existing pavement. It is performed without heat and is generally used as a base course for a new wearing surface. The reclaimed material is mixed with a new binder (usually a SS or MS emulsion) and additives to help restore its original properties, and may also be mixed with some virgin aggregate. The resulting mixture is then placed back on the pavement as a base course, with a new wearing course (AC or chip seal) placed later.

CIR may be limited to the top few inches of the existing pavement, or it may include the full depth of the asphalt layer with or without some underlying base course materials. In the preventive maintenance arena, we are looking at depths of 50 to 100 mm (2 to 4 inches).

Two construction options can be used:

- The single machine process, in which the breaking, pulverizing, and mixing is done by a single machine in a single pass.
- The single-pass equipment train, in which a series of...
This is a schematic illustration of a single-pass equipment train. The first machine mills the existing pavement to the specified depth. The next machine crushes and sizes the reclaimed material. The material is then mixed with new binder and possibly virgin materials and windrowed. Finally, the material is picked up and laid down with a paver.

There is general satisfaction with the use of CIR. New Mexico has used this technique extensively since 1984 and reported excellent performance from a 10-year study. Other states are also reporting good performance in the short term. Where problems have occurred, poor or excessive binder distribution, excessive moisture in the material, or improper project selection were cited as reasons for failure. Again, these are targeted to lower volume roadways.

HIR, sometimes referred to as hot surface recycling, is a process in which the upper few inches of the existing pavement is reworked and reconditioned. This process addresses surficial distresses such as minor cracking, corrugations, bleeding, low surface friction, and rutting (if it is in the surface and not in the base).

There are three available HIR techniques: Heater-scarification is the earliest form of HIR and is a simple process in which the surface of the pavement is heated, scarified with a set of scarifying teeth, mixed with a recycling agent, and then leveled and compacted. The repaving technique heats the existing pavement and mills or scarifies it to a depth of 19 to 25 mm, and then mixes in a recycling agent. This recycled material is then placed as a leveling course and is then followed with a hot mix wearing surface (either immediately or at some later time). The remixing technique removes a portion of the existing pavement and then mixes it with controlled amounts of virgin mix and/or rejuvenating agents in an on-board pugmill, and the resultant mixture is then placed as the new surface course.
This slide shows a photo of a heater-scarifier.

This shows a schematic of the repaving process. The placement of an overlay is an integral part of this recycling process. The existing pavement is heated, scarified or milled. The material is mixed with a rejuvenating agent. Recycled material is placed as a leveling course, followed with a hot-mix wearing surface that forms a thermal bond between the new and recycled layer. (This photo shows a single pass operation, but, alternatively, a separate paver can be used to place the surface course immediately after the laydown of the leveling course or at some time later.)

This photo shows a single pass repaving equipment. The operation is moving to the right.

This slide shows a photo of surface remixing equipment.
Drum mix recycling, a hybrid of the remixing process, uses 100 percent of the existing materials and only requires approximately 4 percent of new materials. The surface is mechanically removed to about 50 mm (2 in). A rejuvenating agent and/or various additives are added and blended in a heated drum mix plant. New aggregate is added in the proper amount and type to achieve a new serviceable mix design.

The performance of HIR is somewhat variable depending on the type of operation. Heater-scarification projects generally last 3 to 5 years, but many have provided 10 years of service. Service lives of 8 to 12 years reported for projects using the repaving process. The remixing process is relatively new, but preliminary results are promising. However, because there are more steps in these HIR processes, there is also greater variability in their performance.

It is important that the existing pavement be at least 75 mm (3 in) thick and have a stable base and subgrade. Any pavement exhibiting variable conditions, such as different performance or varying levels of support, are not candidates for HIR.

The cost of recycling varies significantly depending on the agency, location, contractor experience, project size, and depth. Hot in-place recycling costs are based upon recycling of the top 25 mm (1 in) of pavement. The costs for heater-scarification and repaving include the placement of a 25-mm (1-in) AC overlay during the process. The costs for remixing include the addition of 10 to 20 percent virgin material.
Cold milling is the removal of the existing pavement surface to a specified depth (generally about 50 to 100 mm). It is most commonly used prior to an overlay to restore the profile and cross slopes and to enhance the bonding between the existing pavement and the new overlay. It has also become a standard part of recycling, as it is an efficient means of removing pavement material. Cold milling has occasionally been done as a “stand-alone” treatment in which agencies want to remove a badly rutted or distorted pavement surface and will return in a few years to place a new wearing course.

Performance and Costs of Cold Milling
- Integral part of many overlay projects and most recycling projects.
- Cold-milled surface can last 3 to 7 years.
- Typical costs range from $0.60 to $3.60 per m² ($0.50 to $3.00 per yd²).

Cold milling is an integral part of many overlay projects and most recycling projects. As such, it is difficult to factor out the performance and effectiveness of the cold milling operation on the life of the treatment, although cold milling’s widespread use and popularity speaks volumes. Cold milling is not suitable for pavements with significant deterioration. A cold milled surface occasionally has been used to carry traffic, and when this has been done a service life of 3 to 7 years may be expected. However, the newer equipment with more cutting bits are needed to produce a smoother texture.

The costs of the cold milling operation can vary significantly depending on the depth of removal, type of coarse aggregate, and the size of the project.

Thin HMA Overlays
- Thin (19 to 38 mm) plant mixtures of asphalt cement and aggregate.
- Conventional dense-graded
- Open graded (OGFC)
- Stone Matrix Asphalt

Three different types are available:
- Conventional dense-graded
- Open graded friction course
- Stone matrix asphalt (SMA)

Generally, the purpose of these thin overlays is to restore ride and improve surface friction. Little additional structure is added to the pavement, so it must be in relatively good condition. Additional benefits provided by OGFC are reductions in hydroplaning and tire splash/spray.
The performance of these thin HMA overlays depends on the condition of existing pavement, adequacy of mix design, quality of overlay construction, and traffic levels. Perhaps the most variable in performance is dense-graded HMA overlays, which show service lives of 5 to 10 years. Where failures have occurred, it is often because of its placement on an excessively deteriorated pavement.

OGFC overlays have performed well, with service lives of 8 to 12 years. Because of their open nature, they may be more susceptible to stripping and steps may need to be taken to reduce the potential for stripping (heavier film of asphalt on the aggregate).

No long-term performance data for Stone matrix asphalt overlays are available, but the short term results are promising. The results of an NCAT field evaluation study showed, after up to 5 years of service:

--No appreciable rutting
--No evidence of raveling
--Greater resistance to cracking than adjacent dense-graded

Here are some typical costs for the thin HMA overlay types. These assume overlay thicknesses of about 25 mm (1 in). No cost information is available for SMA, but it is estimated to be about 20 to 40 percent more than dense-graded HMA.
Here are the techniques for PCC-surfaced pavements. Maintenance of drainage features is one technique that is common to both pavement surface types. Again, many of these treatments are also rehabilitation treatments, but they can be used as preventive maintenance treatments.

The first and perhaps most common maintenance technique performed on concrete pavements is joint/crack sealing. The purpose of sealing joints and cracks in concrete pavements is to minimize the amount of water that gets into the pavement structure and also to prevent the intrusion of incompressibles. What distresses can develop if excessive water gets into the pavement? (pumping/faulting) If incompressibles get into the joint? (spalling/blowups) For concrete pavements, the most common sealant materials are rubberized asphalt and silicone.

A variety of sealant placement configurations can be used. Sawed and recessed is the most commonly used configuration. Using this configuration, the existing joint is sawed to the desired width, the joint sidewalls are cleaned, a backer rod is installed, and the sealant material is placed with a slight recess below the surface.

Joint sealants show a wide variation in service life depending on material, climate, and so on. Silicone sealants are expected to provide a longer service life before resealing, and the SHRP H-106 study, after 7 years of evaluations, indicate that silicone sealants have provided the best performance. Results compiled by Geoffrey suggest that regular resealing may extend pavement life by 5 to 6 years. Resealing is most effective on pavements that are in relatively good condition.
Crack sealing on concrete pavements uses techniques and materials similar to those used for joint sealing. One major difference, however, is that cracks are irregularly shaped and may require routing or sawing to establish the sealant reservoir.

The life of crack sealing installations is similar to joint sealing—about 5 years. Hot-poured, rubberized materials are more commonly used.

Crack sealing is most effective on cracks between 3 and 19 mm (0.12 to 0.75 in) wide. Cracks less than 3 mm (0.25 in) do not need to be sealed. Cracks greater than 19 mm (0.75 in) are best addressed by other methods.

Essentially the same materials are used for joint/crack sealing in PCC as in crack sealing in AC. However, the installation costs are generally higher because of increased preparation.

Two surface texturing techniques are available for use on concrete pavements, and each has a specific purpose.

Diamond grinding removes a thin layer of concrete (typically about 6.4 mm [0.25 in]) such that faulting is removed and smoothness and high friction levels are restored. Diamond grinding is most often performed over an entire project; most diamond heads are about 0.9 m (3 ft) wide. The pavement should be in relatively good condition without durability distress.

Diamond grooving creates narrow, discrete grooves in the concrete surface that is intended to reduce hydroplaning and wet weather accidents. Unlike diamond grinding, diamond grooving is often performed at localized areas where wet-weather accidents have historically been a problem (curves, intersections, etc.). Grooving is most commonly performed longitudinally due to ease of construction.
This figure illustrates the typical dimensions associated with each activity. For diamond grinding, the land area depends on the hardness of the aggregate; the idea is that the land area will break off under traffic.

Diamond grooving produces grooves that are more widely spaced.

These photos illustrate the difference between a diamond-ground surface and a diamond-grooved surface.

A recently completed study showed that diamond grinding produces a surface that is as smooth or smoother than newly constructed pavements, and lasts about 10 years. Factors affecting the service life of diamond grinding include traffic loadings, existing pavement condition, climate, and concurrent repair/restoration work such as patching and undersealing.

The pavement may be reground 3 to 4 times without significantly compromising the structural integrity of the pavement. However, if the cause of the faulting is not addressed (load transfer, pumping), faulting can return to significant levels in a few years.

Diamond grooving has shown marked decreases in wet-weather accidents, and these benefits are realized throughout the life of the pavement (the grooves are permanent and do not need to be re-established).

Here are some typical costs for diamond grinding and diamond grooving. The costs can vary substantially, depending upon the hardness of the aggregate in the pavement being ground.
Another preventive maintenance activity for concrete pavements is undersealing, sometimes called subsealing, pressure grouting, or slab stabilization. It is the pressure insertion of a flowable material beneath the concrete slab at areas where pumping and loss of support occur (such as beneath transverse joints and deteriorated cracks). The purpose is to fill the underlying voids and reduce pavement deflections and minimize pumping and faulting. Note, however, that the slab is not to be lifted in this process.

Undersealing should only be performed at joints and cracks where voids are known to exist. The following methods can be used to detect voids:
- Visual distress survey (looking for signs of pumping).
- Deflection testing.
- NDT methods (ground penetrating radar, infrared thermography).
- Epoxy/core method.

Typical costs for undersealing are shown here. These will vary depending on the size of the project, the hole pattern, and the typical size of the voids being filled.

Joint spall repairs, also known as partial-depth repairs, can be used to address joint spalling and other surface defects so that overall pavement rideability can be restored. This technique is most commonly used along transverse joints but can be used at longitudinal joints also. It provides a uniform joint sealant reservoir at repaired areas along joints that will be resealed. A variety of materials may be used:
- Cementitious (PCC or other).
- Polymer-based concrete.
- Bituminous materials.

Only distresses limited to the upper one-third of the slab can be addressed with partial-depth repairs. Distresses that are deeper are more effectively repaired through full-depth repairs.
Only certain types of distresses can effectively be addressed though joint spall repairs. The distress should be limited to the upper one-third of the slab. Full-depth repairs are required for distresses not suitable to joint spall repair.

Joint spall repairs exhibit variable performance due to use on inappropriate distresses or because of poor installation practices.

Typical costs for joint spall repair materials are shown here.

Full-depth repairs differ from spall repairs in that the entire depth of the concrete slab is removed in the distressed area and replaced with new concrete. Distresses that can be addressed with full-depth repairs include transverse and longitudinal cracks, blowups, joint spalling, faulting, and punchouts. In the preventive maintenance arena, FDR may be appropriate for localized areas of pavement that are known or suspected to be deteriorated.
Full-depth repairs should be at least 1.8 m (6 ft) to ensure the extent of deterioration is addressed and to provide a more stable repair that exhibits more slab-like behavior. Smooth dowels should be placed at one or both ends; deformed tiebars can be placed at one end only. The dowels should be placed at mid-depth within the slab.

Full-depth repairs can provide long-term performance when properly designed and constructed. Several FDR projects resulted in poor performance, and most of these early failures were attributed to inadequate design (most notably poor load transfer) or poor construction quality.

For preventive maintenance, the use of high-early strength materials is recommended to allow the pavement to be opened to traffic quickly. The use of a Type III cement, high cement contents, and chemical accelerators (such as calcium chloride) allow opening within 4 to 6 hours.

Typical costs for full-depth repairs are shown here. These costs will vary substantially from location to location and from project to project.

Also known as retrofitted load transfer, load transfer restoration is a technique used on existing jointed PCC pavements that were constructed without dowel bars at the transverse joints. The purpose is to provide reliable load transfer across the joints (and/or cracks) so that pumping and faulting is reduced or eliminated. It is most appropriate for pavements in relatively good condition that do not exhibit significant levels of distress.

Smooth round dowel bars are the recommended retrofitted load transfer device. Others devices have been tried but have not provided reliable performance.
In the load transfer restoration process, slots are saw cut into the pavement. Dowels are placed on supports at mid-depth and backfilled with cementitious material and finished flush with existing pavement.

Dowels are generally clustered in groups of three dowels in each wheelpath. Groups of 4 or 5 dowels in each wheelpath may be required for very heavily-trafficked pavements.

The performance of retrofitted dowel bars has generally been good. Washington State has been one of the leaders in the use of this technology, although many other states (Kansas for example) are now using this technique.
Typical costs for load transfer restoration varies, but on production jobs costs between $25 to $35 per dowel are common.

Because there are many different treatment methods, as well as variations within a treatment method, a methodical approach to the selection of preventive maintenance treatments is recommended. This approach is outlined in this figure and includes a life cycle cost analysis, which will be described in the next module. It should be noted that the expected performance life of each treatment is needed for the LCCA, and this is not always well established for the treatments, particularly under a variety of conditions (traffic, environment).

Timing is a critical factor on the effectiveness of a giving treatment. If performed too early, there is not enough performance benefit to offset the cost of applying the treatment. If performed too late, the pavement is too deteriorated to benefit from the treatment. Unfortunately, at the present time there is little guidance on identifying the right time for applying preventive maintenance treatments, and most agencies rely on policy or on the engineering judgment of experienced field personnel.

This module has presented a broad overview of the available preventive maintenance treatments for both AC and PCC pavements. It is not intended to provide detailed design and construction information for each technique, but rather to present the different techniques and provide some general information as to what they address and when they might be used.

A summary table of the various techniques is provided in the reference manual at the end of module 3.