CAIT-UTC-REG11

# Pavement Design for Local Roads and Streets

FINAL REPORT
November, 2020

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Rutgers, The State University of New Jersey
And
U.S. Department of Transportation
Federal Highway Administration

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TECHNICAL REPORT STANDARD TITLE PAGE

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| CAIT-UTC-REG11 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| Pavement Design for Local Roads and Streets | November, 2020 |
| | 6. Performing Organization Code<br>CAIT/Cornell University |
| 7. Author(s)<br>David P. Orr, PE, Ph.D., http://orcid.org/0000-0001-8797-3208 | 8. Performing Organization Report No.<br>CAIT-UTC-REG11 |
| 9. Performing Organization Name and Address<br>Cornell University<br>416 Riley-Robb Hall, Ithaca, NY 14853 | 10. Work Unit No. |
| | 11. Contract or Grant No.<br>69A3551847102 |
| 12. Sponsoring Agency Name and Address<br>Center for Advanced Infrastructure and Transportation<br>Rutgers, The State University of New Jersey<br>100 Brett Road, Piscataway, NJ 08854 | 13. Type of Report and Period Covered<br>Final Report<br>10/1/2018 – 12/31/2019 |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes
U.S. Department of Transportation/OST-R
1200 New Jersey Avenue, SE
Washington, DC 20590-0001

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| 17. Key Words | 18. Distribution Statement |
|---|---|
| Low-volume, pavement design, seasonality, farm equipment, mechanistic-empirical | |

| 19. Security Classification (of this report) | 20. Security Classification (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 21 | |

**Form DOT F 1700.7** (8-69)

# Pavement Design for Local Roads and Streets

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## Abstract

Low-volume roads (LVRs) make up more than half the centerline mileage in the United States, most of which are not designed. The Cornell University Local Roads Program worked with local highway agencies New York State to develop a mechanistic-empirical pavement design tool that overcomes the limitations of expertise and time of most LVR highway officials but takes advantage of the knowledge of their own LVRs. The tool developed, *RoadPE: LHI*, uses two common pavement fatigue criteria, surface tensile strain and subgrade vertical strain, with simplified inputs, and built-in trend analysis to determine the thickness of the asphalt layers for overlaid, mill and filled, rehabilitated, and reconstructed LVRs.



## Acknowledgement

The authors would like to acknowledge to financial support of the USDOT Region 1 University Transportation Center.


# Description of the Problem

Local roads are a majority of centerline mileage, but pavement design is not usually done. (*1*) Instead, most local agencies just use a default design for all of the roads in their system. In some cases, the pavement may have the correct thickness, but in many other cases, the pavement is not thick enough for the site and traffic conditions or the pavement is thicker than necessary. An excess thickness is preferred since it will last longer, but at an average of $100,000 per inch per mile for a new hot mix asphalt pavement, the excess costs can become problematic. If the pavement is too thin, then the road fails prematurely and there are excess costs due to rough roads that are borne by the traveling public.

Small highway agencies are managed by non-engineers who have good knowledge of their road system. They need a simple tool that gives a reasonable design that accounts for the traffic conditions in their municipality.

## Pavement Design Methods

When designing any highway, the first question is what is a road pavement? (*2*) A road spreads out the forces of passing vehicles such that the subgrade does not fail prematurely. (*1*) The majority of the current design tools available use empirical methodologies or require overly complicated data inputs. (*3-6*) There are four general pavement design methods: experience, catalog, empirical, and mechanistic-empirical.

### Experience

Experience-based methods are still very commonly used, especially by smaller agencies. They use only a few different designs for the pavements in their system. For example, an agency might have one thickness for residential streets, one for commercial streets, and another for other roads in the system.

If the highway manager has enough experience, this method can be successful as it slowly evolves to the thicknesses that work in a particular community. However, it typically overdesigns the thickness to be sure it will not fail or is too thin because the manager paves as much as they can afford with the limited funds available in the budget. An experience-based design cannot handle large variations in traffic volume and there is generally no rational basis for the thickness.

**Catalog**

A catalog-based design is usually the result of one of the other methods. The highway manager prepares a table of designs for various conditions and inputs. These may be experience-based, or utilize an engineering tool to develop the table of designs.

The New York State Department of Transportation (NYSDOT) Comprehensive Pavement Design Manual (CPDM) is a catalog-based design that uses the AASHTO '93 Pavement Design Guide as the engineering model determination of the thicknesses. (*3; 7*) The NYSDOT used the AASHTO '93 guide and generated a series of default values to create a chart of design thicknesses for various subgrade conditions, traffic loading, and surface types. (*8*)

To use the CPDM, the designer needs to decide if the surface is to be asphalt concrete (HMA) or Portland Cement Concrete (PCC), calculate a 50-year count of Equivalent Single Axle Loads (ESALs) using a simplified formula, and determine the subgrade resilient modulus, $M_r$. Then using the proper table for HMA or PCC, the designer can select the thickness of the new pavement.

For example, if a new road has a subgrade modulus of 5,950 psi (41 MPa) and a 50-year traffic count of less than 6 million ESALs, the designer uses the proper figure and table and would select final thicknesses as shown in Table 1.

**Table 1. LVR Design over weak subgrade, NYSDOT CPDM**

| Layer | Thickness | Notes |
|---|---|---|
| Hot Mix Asphalt Concrete (HMA) | 165 mm (6.5 inches) | Table 4-5 in CPDM |
| Asphalt treated permeable base | 100 mm (4.0 inches) | Only shown in figure |
| Granular subbase | 300 mm (12 inches) | Only shown in figure |

Therefore, the minimum thickness for an LVR is 22.5 inches (565 mm). Such a catalog system can be an effective way to generate an initial design, but it may not be precise enough or have enough variations to deal with real-world site conditions. For most local agencies, such a design is almost impossible to build, with the HMA asphalt layers alone projected to cost over $650,000 per mile.

**Empirical**

As mentioned, the NYSDOT CPDM uses the AASHTO '93 Pavement Design Guide which is an empirical design tool and is still very commonly used for pavement design. For the AASHTO '93 Guide, the equations were derived using the results of the AASHO Road Test in Ottawa, Illinois. (*9-11*)

Tables and information are available to determine the expected values for the variables including $M_R$, the subgrade resilient modulus. The subgrade is the only layer that has a seasonal component in the AASHTO '93 Guide. To determine the seasonality, the designer uses an equation to calculate the relative damage on the subgrade modulus, determines the average relative damage, and from this, the average roadbed resilient modulus.

Chapter 4 of the AASHTO '93 *Pavement Design Guide* discusses Low-Volume Road Design and includes a catalog "when the more detailed design approach is not possible." (*7*) For the northeastern U.S., the characteristic design is a wet hard-freeze, spring thaw condition.

Using default values for the structural layer coefficients from NYSDOT and assuming a 12-inch granular base, the HMA thickness can be calculated. The range of HMA thickness for an LVR road ranges from 1.7-6.4 inches in New York State, which is significantly less than the 10.5 inches of asphaltic material for the lowest volume roads in the NYSDOT CPDM.

### Mechanistic-Empirical

The last of the pavement design methods is mechanistic-empirical (M-E) design. While some think a fully mechanistic design is possible (*12*), most realize that the problem is too complex and a combined approach is the most likely to be successful. (*13-15*)

The concept is to use a mechanistic approach to determine the critical stresses and strains and empirical methods for a fatigue failure model. The mechanistic approach requires the calculation of the stresses and strains due to various traffic loading for the pavement layer structure. While a non-linear approach may be used, for LVR pavements a linear approach is acceptable. (*16; 17*)

The overall cost and complexity of the AASHTO ME Design is a barrier to its use. While the concepts in the ME Design are valid and useful for higher volume roads, Irwin and Orr recommended removing the LVR section from the new ME-Guide. There are too many details for the occasional use typically done by LVR designers. (*18*)

### Why Develop a New Design Method

While an experience or catalog-based approach may work form many small agencies, when reviewing what local agencies where actually using, the authors found that the variations in traffic and environment were greater than the limited ranges available in the current design tools. A new tool was needed to allow for agencies to account for the conditions and properly account for the seasonality of low-volume pavements. A tool utilizing mechanisitic-empirical methods was choisen as it had the most capability. The tool has to balance the accuracy of the design with the accuracy of the actual design.

## Development Process

The Cornell University Local Roads Program (Cornell) worked with local agencies to understand their capacity for data collection for the critical factors in pavement thickness design. For those design factors not accounted for by a local agency, defaults needed to be set up.

The research was focused on the development of a simple to use tool that would allow a small, local agency to develop a mechanistic-empirical design for low volume roads and streets. After speaking with the anticipated users of the tool in small towns and counties in New York State and working with them on the development of a frost depth modeling tool, the primary focus for the tool was for pavement overlays and rehabilitation, but new road design was also included.

The final product is a tool in a spreadsheet form that allows an LVR highway manager without an engineering background to determine a reasonable pavement design. The tool also provides information for a professional engineer should they become involved due to site conditions, traffic, or other critical factors.

The project tool allows the end-users to design the thickness of an LVR that will meet their needs using the tools and information they have readily at hand. Where this project stands out is in its use of mechanistic-empirical methods, but in a simple, user-friendly way. The design inputs were selected in consultation with the local highway community. This means the user will not need extensive tests from outside labs. It also means the tool is likely to be less precise than more sophisticated tools. However, the local agencies involved in reviewing the tool made it clear a simple tool that they could use would be better than a more precise tool which was so complicated or expensive that it did not get used. Flexible Pavements of Ohio (FPO) also showed that simple design tools for LVRs would be more likely to be used. (*19*) A simple tool with less precision is better than a tool that is not used due to its complexity.

**Pavement Design Tool Development**

In the previous decades, Cornell had been developing seasonal models of pavement analysis and evaluation. Orr and Irwin showed how a representative year could be used to account for the seasonality of every layer in a pavement design. (*20*) Duffy, Orr, and Miller updated the frost model used to improve the timing of the thawing period. (*21*) Orr, Mug, and Duffy used the updated frost model to develop a simple-to-use spreadsheet tool that would allow local agencies to determine when to post their highways for spring load restrictions. (*22*) It was during this time, during discussions with the local agencies using the frost depth model, that Cornell realized most local agencies would not design a pavement unless the inputs were simple and the outputs were reasonable. Using this strategy, Orr showed how a simple tool could allow local agencies to determine when to post local roads. (*23*)

A draft spreadsheet-based tool was developed that incorporated the lessons learned from both direct feedback from the local highway community, and the experience with the frost depth tool. During this phase, a set of agencies were selected to provide feedback and testing of the beta version of the tool. Agencies were sent draft copies of the tool and provided feedback on the ease of use and the applicability of the model.

**Limitations of LVR Design**

As the tool was being finalized, the discussion centered around two issues: would an LVR design tool be used and what is the upper limit of the traffic volume where the tool should be used.

- Would the tool be used?

  When sharing the draft tool with local agencies, the answer was yes. Local agencies wanted a simple and easy to use design tool, but it could not require a large amount of new testing. It would need to evaluate existing roads, and calculate the thickness of overlays and mill and fill overlays as they are the most common major work done. If possible, the tool should include rehabilitation of the base. None of the local agencies were worried about replacing the subgrade. In cases where this needed to be done, an engineer is usually involved, and a more sophisticated design could be used.

  The other issue was time. The tool needed to be easy to use and not take a lot of time to learn to use or to obtain a pavement design.

- Upper limit on traffic volume?

  As most agencies do not know the percentage of trucks, the total number of vehicles per day was a better measure of the upper limit to use with the new design tool. The initial draft of the tool had a limit of 1,000 vehicles per day (vpd), but county agencies needed to account for a little more traffic. Preliminary results showed that the calculations would still be precise enough at a higher level of traffic.

  In the summer of 2019, AASHTO released the 2$^{nd}$ Edition of the *Guidelines for Geometric Design of Low-Volume Local Roads* (*24*) with an upper limit of 2,000 vpd. This value fit into both the need and capability of the new tool and was chosen as the recommended upper limit.

**Final Tool**

The tool was built in Microsoft Excel (*25*) and the primary output from the project is named *RoadPE: LHI*. *RoadPE* is the name of a series of pavement analysis tools developed by Cornell over the past 20 years. The *LHI* stands for Low-volume Highway Inputs as a reminder that these inputs are only valid for low-volume roads. All the primary calculations and data are available for inspection and review by users. The spreadsheet tool is available for download from the New York State LTAP Center. A screen shot of the existing pavement inputs from the tool is shown in Figure 1.

**RoadPE: LHI - Low-volume Highway Inputs for Pavement Design**

| | | |
|---|---|---|
| Location: | | Input all known data. |
| Route: | | Blue cells must be filled out. |
| Designer: | | Green cells are drop down list to be chosen by the user. |
| Date: | | Yellow cells are optional inputs. |
| | | Purple cells are defaults that may be changed by the user. |
| | | Orange cells are calculated. |

| Existing Pavement | | | |
|---|---|---|---|
| Layer | Layer type | Thickness | |
| # | | in | |
| 1 | | | Cold Mix Asphalt, Gravel surface, Hot Mix Asphalt |
| 2 | | | Crushed gravel/stone (clean), Dirty unbound base (wet), Stabilized, Uncrushed gravel (clean) |
| 3 | | ∞ | Clayey subgrade , Gravelly subgrade, Sandy subgrade, Silty subgrade |
| Drainage Quality | | | Good, Fair, Poor |
| Age of current pavement (last major work) | | | years |

| Site Inputs | | | | |
|---|---|---|---|---|
| **Seasonal Inputs** | Winter | Thaw | Spring | Summer |
| Length of Season (days) | | | | |
| Avg. Air Temperature (°F) | | | | |

| Traffic | | |
|---|---|---|
| Deisgn Life | | year |
| Current vehciles / day | | vehicles per day |
| Growth Rate | 1.0% | NYSDOT Default = 1% |
| Traffic Type | | Standard LVR, Agricultural, Industrial, Residential, Commercial |

**Figure 1. RoadPE:LHI - Existing Pavement Inputs**

The choice of Excel was done for three reasons. First, while macros may be disabled by some IT departments, most of the local agencies felt this would not be an issue. Secondly, by using Excel, all the calculations are available for anyone to review and provide improvements. The protection on the sheets is only there to keep a user from accidentally deleting a critical calculation. Third, by using a tool many local agencies are already using, the instructions for use could utilize the common forms for use of any spreadsheet tool. If there was a demand in the future, a self-standing version could be developed.

# Low Volume Pavement Design Inputs

Since very few LVRs are new, the first steps are the evaluation of the existing pavement and identifying the critical variables for LVR Design. To make the new tool, *RoadPE: LHI,* work, defaults for the detailed data, which could not be provided by the local highway community, had to be obtained or calculated. The input data needed and obtained by the local agency for an LVR include the pavement structure, traffic, design life, and site conditions. There are many assumptions in using the tool, but these variations were reviewed to reduce the errors to a reasonable level. The tool is not a replacement for a more sophisticated tool such as the ME-PDG which is needed for higher volume roads.

**Pavement structure**

Almost every LVR consists of no more than three layers, including the subgrade if the asphalt surface is counted as a single layer. For each of these three layers in the existing pavement, the user needs to input the layer type and the thickness, with the exception for the subgrade which is considered a semi-infinite half-space. Default seasonal moduli and Poisson's ratio value are included for each material type. User inputs include the thickness of the pavement layers as well as the quality of drainage. All the defaults are provided to the user on various pages within the spreadsheet tool. The four seasons in the representative seasonal year are shown below and derived from maps developed by Orr and Irwin (*20*) and updated by Orr, Mung, and Duffy (*22*). The development of the seasonal maps is outlined in those two references. Weather data for the previous 20 years was obtained from the Northeast Regional Climate Center (NRCC) and used to generate the seasons for a grid of data provided. The average seasonal lengths and frost depths for each point were then kriged using ArcGIS to produce the maps for the area in and around New York State. Generating a similar map is feasible for any location. NRCC also provided climate prediction data for the next 20 years to determine the effects of climate change. The 20 year average data is slightly conservative with regard to pavement thickness design.

- **Winter** is the period when at least 4 inches of the subgrade is frozen and there is no thaw in any unbound layer. This is not a continuous season. During January thaws, the upper unbound layers may be thawed with a frozen layer below. This condition is considered part of the thaw season.
- **Thaw** occurs whenever there is any thaw in the unbound layers and some lower portion of the pavement is still frozen.
- **Spring** is the period after the pavement has completely thawed until evaporation exceeds precipitation.
- **Summer** is the period after evaporation exceeds precipitation until winter. Due to a lag in the movement of moisture, it is not expected to start until one month after the evaporation exceeds precipitation.

**Material Type**

Local agencies can choose between hot-mix asphalt concrete (HMA), cold-mix asphalt concrete (Cold mix), or gravel surfaces. The tool works for gravel surfaces but only utilizes the rutting fatigue failure criteria. For the base, they usually know if it is clean or dirty, crushed or uncrushed, and if the layer has been stabilized with asphalt or concrete in the past. The subgrade is not tested and most agencies do not use soil maps. (*26; 27*) The most an agency is usually able to state about the subgrade is the general classification of gravely, sandy, silty, or clayey.

A table of default values was developed for these choices of material types using results from the AASHTO ME PDG, default data collected by Irwin, and results from the seasonal in-situ pavement analysis study carried out by Cornell. (24)

**Thickness**

Thickness is one of the outputs of the design, but it is also necessary to know the thickness of the existing pavement structure. Variation in the surface can be a significant issue so a conservative approach is recommended. (*28*) For existing pavements, the thickness can be determined using cores, test pits, or GPR.

While the user is only required to input the subgrade material type, the tool uses the frost depth input to adjust the modulus of the lower subgrade below the active frost zone. While the depth of frost varies from year to year, the effect on the design is limited if the deeper, and typically stiffer, lower subgrade is considered. For a deep fill, the user should use a gravelly subgrade.

#### Drainage

The local highway official usually knows if the drainage is good, fair, or poor in quality. The default moduli are modified using a simple multiplier from the defaults based upon the material type.

#### Age of Pavement

The age is not accurately known in many cases, but a general estimate can be obtained by the local highway official.

### Traffic

Traffic counts for LVRs are not usually done and while it is recommended, it is not likely to be as detailed as is needed for the AASHTO ME PDG. Instead, estimation methods are typically used.

#### Traffic Volume

The NYS LTAP Center has a *Quick Answer* on traffic counts which provides three ways to obtain a quick count of the traffic without a traffic counter. (*29*) This method works since the busiest time of the day sees 15 percent of the traffic in rural areas and 11 percent in urban areas. (*30*) Combined with local knowledge of traffic it is possible to obtain a good estimate of total volume.

#### Traffic Spectra

The traffic spectra have a major influence on the life of the pavement. Using information from LTPP (*31*) and the new AASHTO ME PDG, it is possible to develop default traffic spectra for LVR roads using the groups from the ME PDG and LTPP.

The starting point for the analysis is the Intermediate light and single-trailer truck route from the AASHTO ME PDG. The details for the trucks in that traffic distribution is shown in Table 2. The amount of trucks is typically about 12.5 percent (1/8$^{th}$) of the overall traffic. For an LVR with 2,000 vpd, or 250 trucks per day, this equates to the following breakdown of the number of trucks per day in each class as shown.

LVRs are very unlikely to see the multi-unit trucks except for agricultural equipment. Calculations were run to determine the change in the design using the small percentage of trucks in classes 7 and 10-13. Except for some agricultural equipment scenarios, there was no difference found in the overall design if instead of the breakdown shown in Table 2, the counts for classes 7 and 10-13 were assumed to be class 9.

The loads for the various truck configurations vary in real traffic, but for an LVR, a standard axle load and number of axles per truck were set up using a report on the verification of the LTPP vehicle classification rules from FHWA Research and Technology. Triple axles were not included but might be included in future versions of the tool.

**Table 2. Intermediate Light and Single-trailer Truck Route Truck Class Distribution (%) and Trucks per day at 2,000 vpd**

| Group and Description | | Truck Class Distribution (%) (FHWA Designations) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 12 | Percentage by Class | 3.9 | 40.8 | 11.7 | 1.5 | 12.2 | 25.0 | 2.7 | 0.6 | 0.3 | 1.3 |
| | Trucks per day at 2,000 vpd | 10 | 102 | 29 | 4 | 31 | 63 | 7 | 2 | <1 | 3 |

One of the traffic challenges is the large variation in the percentage of trucks in the traffic flow. Discussing the possible types of traffic, the four types of traffic noted by the local highway community are agricultural, commercial, industrial, and residential.

- Agricultural
  A mix of twice as many trucks as typical with more dual-axle single-unit trucks, but also more single-axle trucks with trailers.
- Commercial
  Almost one-third trucks, with fewer single-axle, single-unit trucks, and more semi-trucks with dual-axle trailers.
- Industrial
  Almost 50 percent of trucks with a large percentage of dual-axle single-unit trucks.
- Residential
  Very small percentage of trucks, more buses for schools, and less dual-wheel semi-trucks with trailers.

Including the Standard LVR traffic distribution, these are the five traffic distributions available in *RoadPE: LHI*.

### Growth

Most LVRs experience very little growth in traffic and the NYSDOT default of 1 percent is usually adequate and probably conservative for most LVRs.

### Wheel Wander

The AASHTO ME PDG default is also considered adequate. While LVRs are typically narrower which might reduce wheel wander, the lack of traffic lines on most local roads tends to counter this effect. The AASHTO ME PDG default of 10 inches is used in *RoadPE: LHI*.

For each traffic loading, the wheel wander must be accounted for while balancing computing time and accuracy. After several analyses, it was determined that four-wheel offsets would be enough to complete the task. The wheel wander is broken into 7 bins (three on each side of the wheel centerline) with the outer bin assumed to have all the traffic not included in the central bin locations.

## Design Life

While NYSDOT is designing for 50-years, most LVRs are designed for a much shorter lifespan, even for a new road. (*1*) A new road may be designed for a 25-year life, but a 10-year life is more common for an overlay or mill and fill operation. This is a user input value.

## Weather and Site Conditions

When rolling out its frost depth tool, Cornell found many agencies may be able to download or obtain short term data for a given year to use in the daily frost depth model. However, obtaining more than that would be unlikely. Also, many agencies are not aware of the pavement seasons other than spring thaw. Maps showing the various seasonal lengths and associated temperatures using a representative year concept were generated and included with the tool.

Orr showed that there is a need to include seasonality in every layer in a pavement, not just the subgrade as is varied in the AASHTO '93 Guide. (*32*) This is not a new concept and many others have made this conclusion and it is also part of the new AASHTO ME PDG.

### Site Inputs

As mentioned, *Road PE: LHI* uses a representative year approach. A user needs to select eight seasonal inputs, four seasonal average air temperatures, and the depth of frost as shown in Table 3. The length of the summer season is calculated automatically.

**Table 3. Example Site Inputs in Road PE: LHI**

| **Seasonal Inputs** | Winter | Thaw | Spring | Summer | Depth Frost |
|---|---|---|---|---|---|
| Length of Season (days) | 23 | 16 | 88 | 238.3 | 3.2 ft |
| Avg. Air Temperature (°F) | 19 | 33 | 46 | 57 | |

Figures for the average seasonal lengths and average air temperatures were generated by Orr and Irwin for a typical LVR road and are provided for the user. The frost depth data was updated by Orr, Mung, and Duffy as part of the development of the frost depth tool (Figure 1).

Using these data and maps, it is possible to calculate the effect of changing seasonal lengths in different locations. For instance, a pavement in Rockland County, where the typical spring thaw length is 7 days long, might lead to a total number of allowable load repetitions of 660,000 ESALs. The same pavement with the same initial inputs, but in Albany County where the expected number of days of thaw is 28, would only have an allowable number of load repetitions of 490,000 ESALs. This is a 26.2 percent decrease in lifespan!

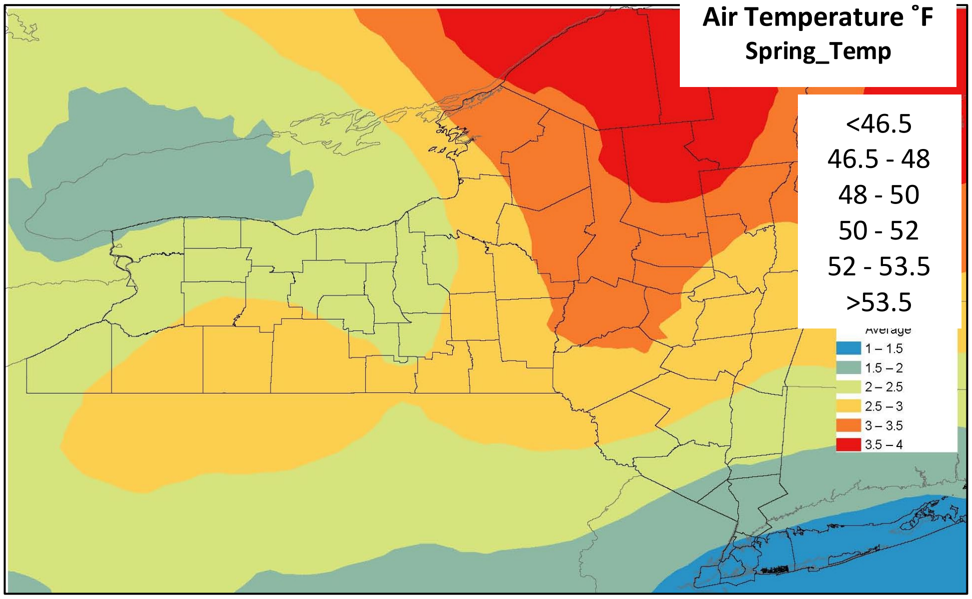


**Figure 2. Average Expected Frost Depth Under LVR (ft)**

# Running an LVR Analysis

Once the design inputs are collected and put into *RoadPE: LHI,* the user is ready to run an analysis of the existing pavement or a possible new design. The tool calculates the critical strains at the bottom of the asphalt layers (and overlay if one exists) and at the top of the subgrade using the inputs from the user to gather critical values about the pavement structure.

## Failure Criteria

While there are numerous fatigue failure modes, the two most commonly used are the tensile strain in the surface which leads to cracking and the vertical strain on the subgrade which leads to rutting. (*33*) For an LVR, these two criteria were determined to be adequate for a pavement design.

Irwin (*33*) collected a series of failure curves from various agencies including the Asphalt Institute, Transportation Research Laboratory (TRL) from the UK, Shell Oil, Denmark Technical University (DTU), NAASRA (formerly National Association of Australian State Road Authorities and today Austroads), and Dorman & Metcalf. The average value for the surface equation is very similar to the new ME-PDG.

The average values of Irwin and the new AASHTO Guide are listed below.

$$N_{fsurface}(10^6) = \left(219.90\left(\frac{E}{435{,}000\,psi}\right)^{-0.85}\frac{1}{\varepsilon_t}\right)^{4.263}$$

$$N_{fsubgrade}(10^6) = \left(618.60\frac{1}{\varepsilon_V}\right)^{3.902}$$

Where

$N_f$ = number of cycles to failure (usually in millions of cycles)
$E$ = modulus of the surface layer
E' = reference modules for the bound surface layer
$\varepsilon_t$ or $\varepsilon_v$ = critical strain (microstrain)

These average values are used in the final tool.

## Invoking the Forward Calculation Engine

The forward calculation engine is CHEVLAY3, a Windows 10 version of the CHEVLAY2 engine developed by the Chevron Oil Corporation and upgraded to a 16 point quadrature by Irwin to improve accuracy. (*34*) For dual-wheel loads, supposition is used to determine the critical stresses and strains. The offset data due to wheel wander are determined in a similar fashion.

For each of the 52 calls, the surface and subgrade strains are determined and the allowable number of load repetitions, $N_f$, are calculated. The number of expected or actual traffic load repetitions, $n_f$, are also calculated and damage factors, *D*, are determined. All the *D* factors are summed, and a final *D* value is determined using Miner's Hypothesis for both the surface and subgrade layers.

$$D_{analysis} = \sum_{i=1,j=1,..}^{T,season,...} D_{i,j,...}$$

## Existing Pavement

Designing a pavement repair requires an initial run to determine the amount of current damage already consumed by the existing pavement. If the $D_{existing}$ is greater than 1.0, the existing pavement is already failed, and a reconstruction or rehabilitation is needed.

Four types of work are available to the user of *RoadPE: LHI*, overlay, mill and fill, rehabilitation, and reconstruction. How these are invoked is listed below, but the tool is primarily focused on the design of the asphalt layer thickness. The user can modify the granular layers, but defaults are provided.

## Calculating the AC Thickness

The asphalt thickness can be determined in three analyses using an idea discovered by Richter *et al*. (*28; 35*) The relationship between an overlay thickness and the percentage of life used, *D*, in a semi-log space is very close to linear. It is slightly curvilinear but is conservative. Figure 2 shows the trend line for an LVR pavement with 78 percent of the life already consumed for the existing pavement. The x-axis shows the total life used assuming various overlay thicknesses.

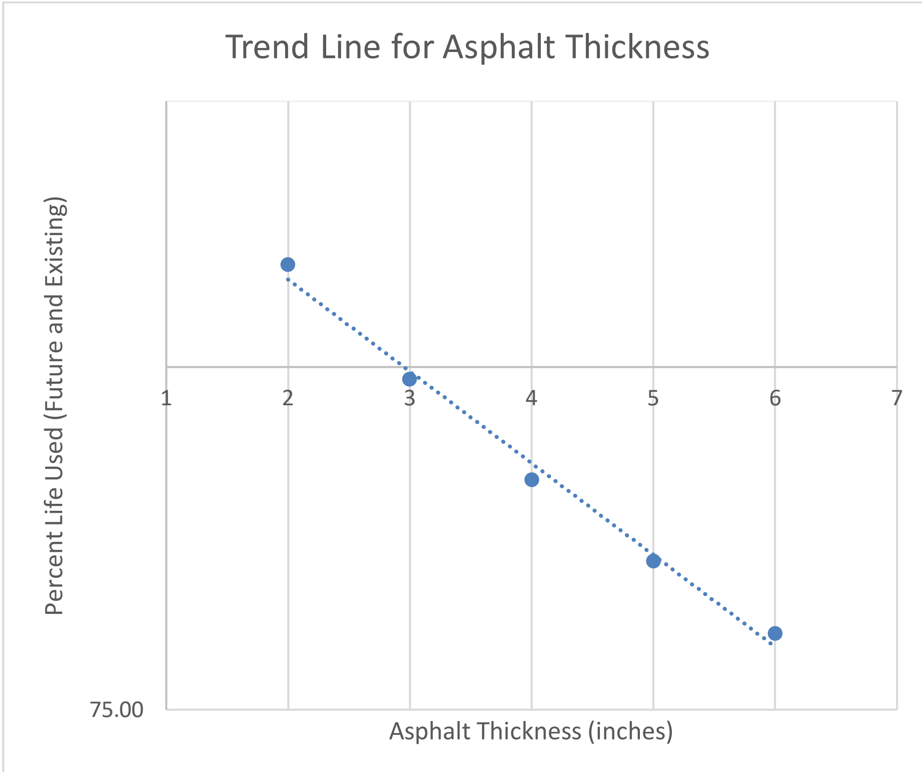


**Figure 3. Trend Line for Asphalt Thickness**

Using a bracketing approach, the tool calculates the expected life consumed for a thin lift of asphalt (2 inches) and a thick lift (6 inches) and calculates the thickness needed to have the total life consumed (*D*) to be less than 1. In this case, the 2-inch lift reduces consumption over the life of the pavement and only another 31 percent is consumed, but this is still too much with a total *D* value of 109%. A 6-inch lift consumes only 2 percent and is too conservative with a total *D* value of 80%.

Assuming a straight line in a semi-log space, the overlay thickness is determined to be 3.08 inches. Since pavements are not built to that level of tolerance, the tool rounds up the thickness to the closest ½ inch; 3.5 inches of asphalt concrete is needed. The tool does one final check to confirm the 3.5-inch lift is adequate. This entire operation of three trials takes only about a minute on a moderately powerful computer.

The minimum thickness of the asphalt layer is 1.5 inches since anything thinner is more of a membrane than something providing structural strength. Three locations in the pavement need to be reviewed in the final check, the existing bottom of the asphalt layers, the bottom of any overlay layers, and the top of the subgrade.

### Type of Work

Four types of work are included based upon conversations with the local highway community.

- Overlay
  An overlay assumes a new lift of asphalt over the existing asphalt surface.
- Mill & Fill

In this case some or all the asphalt surface is removed.

- Rehab

  In this case, the asphalt is either removed or blended into the existing base. The default thickness is 8-inches of rehabbed material which will be assumed to have the same quality as a high-quality stone base. The user may input a different thickness for the rehabilitation layer.

- Reconstruct

  Assumes existing pavement will be removed to the subgrade and the subgrade will be treated and repaired such that the existing life consumed can be ignored.

**Case Study**

After inputting all the existing pavement information, the user first checks the capacity of the existing pavement. If there is existing capacity, the user selects the type and work and the tool calculates the effects of the 2 and 6 inch final asphalt surface and then uses the bracketing approach discussed above to determine the final calculated thickness. The tool does a final check of the thickness rounded up to the closest ½ inch. Figure 4 shows the results of the overlay analysis. The calculated thickness was 5.22 inches, but after rounding the thickness is 5.5 inches.

| Program will supply design thickness of the new asphalt concrete layer. | | | | | |
|---|---|---|---|---|---|
| | Trial | 1 | 2 | 3 | 4 |
| | | Existing | 2" | 6" | **Calculated** |
| Layer | Layer type | Thickness | Thickness | Thickness | Thickness |
| # | | in | in | in | in |
| | New Asphalt Layer | | 2.0 | 6.0 | **5.5** |
| 1 | Cold Mix Asphalt | 3.0 | 3.0 | 3.0 | 3.0 |
| 2 | Uncrushed gravel base (clean) | 12.0 | 12.0 | 12.0 | 12.0 |
| 3 | Silty soil subgrade | 23.4 | 23.4 | 23.4 | 23.4 |
| | Life (years) | 13 | 25 | 25 | 25 |
| | Drainage | Poor | Fair | Fair | Fair |
| | | 3 | 2 | 2 | 2 |
| Lifespan consumed | AC Overlay | | 0% | 1% | 1% |
| | AC Existing | 91% | 39% | 3% | 4% |
| | Subgrade | 61% | 7% | 1% | 1% |
| | | | | | |
| | Life Used (percentage) (Existing + Future) | | 130% | 94% | 95% |
| | Trend | | 0.11 | -0.03 | |
| | | | | | 5.22 |
| | Life (Calculated in years) | 1 | | | 26 |

**Figure 4. Results of Overlay Analysis**

# Conclusions

Low-volume roads (LVRs) make up more than half the centerline mileage in the United States, but most are not designed. Experience, history, and what the elected board will fund are by far the most common design methods for LVRs. Some agencies have catalogs or standard designs, but these tend to be over or under-designed as they do not consider the actual traffic and site conditions. There is a clear need for a design tool for LVRs.

The other major impediments to doing an actual design on an LVR are expertise and time. Most LVR highway officials have no training in pavement design and even those that do have very little time to spare. If there was a good design tool that worked with the expertise of LVR managers and would allow designs to be done quickly, it would be more likely to be used.

Modern pavement design uses a mechanistic-empirical (ME) design approach, but the AASHTO *ME Pavement Design Guide* (ME PDG) is relatively complex and requires both time and expertise that most LVR managers do not have. While the ME PDG considers many different failure criteria, the two common pavement fatigue criteria of surface tensile strain and subgrade vertical strain are adequate for LVRs.

The available inputs for an LVR road are generally less extensive than a major road, but if well thought out, are still adequate for a design. The LVR pavement only needs to be within the closest ½ inch for an asphalt layer and even if the design is slightly non-conservative it will still serve the public better than the existing methods for choosing the thickness of the pavement layers.

*RoadPE: LHI* overcomes most of the conclusions found during the project and listed above. It is not a precise as the ME PDG, but it meets the needs of LVR highway officials on their level. It includes smart features to take advantage of the needs of the LVR community and the knowledge and expertise of LVR managers.

This first edition of *RoadPE: LHI* will need to be updated as more knowledge is gained and as the tool is used. The tool is not static and should adapt over time to meet the needs and wants of the LVR community.

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