ECONOMIC EVALUATION OF PAVEMENT MANAGEMENT DECISIONS

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ABSTRACT
The Washington State DOT (WSDOT) was an early pioneer in the implementation of pavement management, starting with pavement condition data collection in 1969, and the establishment of a computerized pavement management system in the late 1970's. WSDOT performs a Life Cycle Cost Analysis (LCCA) for all new pavement structures, and existing pavements requiring reconstruction. A 50-year analysis period is used to consider all maintenance and/or rehabilitation activities anticipated over the life cycle analysis period.

The LCCA performed when selecting a pavement type for a new pavement structure is a long-term analysis, based upon the best available information at the time the decision is made. But, it is not an operating plan that lays out the pavement treatment decisions for the next 50 years.

The focus of this paper is the economic evaluation of pavement management decisions made in year-to-year operations, which are based on analyses at the performance period level. The use of economic evaluation techniques such as Cost Effectiveness Analysis, Replacement Analysis, and Break-Even Analysis is essential in making pavement management decisions, and can result in substantial cost savings. Even a one-year extension in pavement life through the use of cost-effective pavement treatments can have significant benefits. The information provided by the economic performance measures are shown to be critical for the efficient planning, prioritizing, and programming of pavement asset management activities.

BACKGROUND
In 1993 the Washington State Legislature enacted into law (RCW 47.05) the requirement that Life Cycle Cost Analysis (LCCA) be considered in the management of the state highway system. This formally established a requirement that had long been standard practice at the Washington State Department of Transportation (WSDOT) through its pavement management practices. WSDOT was an early pioneer in the implementation of pavement management, starting with pavement condition data collection in 1969, and the establishment of a computerized pavement management system in the late 1970's *(1)*.

WSDOT performs a LCCA for all new pavement structures, and existing pavements requiring reconstruction. A 50-year analysis period is used to consider all maintenance and/or rehabilitation activities anticipated over the life cycle analysis period, using a Discount Rate of 4%. The FHWA RealCost *(2)* software is used to perform comparisons among different pavement types, and perform sensitivity analyses regarding the conditions under which certain pavement alternatives have the lowest life-cycle cost.

In performing a LCCA, assumptions must be made concerning the expected pavement performance. The level of service (LOS) at which a rehabilitation intervention is triggered is a key decision variable. At WSDOT a minimum acceptable LOS is assumed, and the objective function for optimization is to satisfy this performance constraint at the lowest possible life-cycle cost. This differs from an alternate approach that maximizes pavement performance (e.g. highest area under the curve) given the available budget as a cost constraint.

The estimated life (time period to rehabilitation intervention) of a particular pavement treatment is assumed in the LCCA based on previous site-specific experience. In Washington State the performance period for a typical 1.8-in. (45mm) asphalt overlay averages 16.9 years in the western part of the state (where climatic conditions are mild), but the standard deviation is 7.3 years *(3)*. This is a significant variation in expected life, especially when considering that multiple performance periods are combined to evaluate a 50-year analysis period.

The traditional LCCA performed when selecting a pavement type for a new pavement structure is a long-term evaluation, based upon the best available information at the time the decision is made. But, it is not an operating plan that lays out the pavement treatment decisions for the next 50 years. The focus of this paper is describing the economic evaluation of pavement management decisions that are made in year-to-year operations, which are based on analyses at the performance period level (where a performance period is defined as the time period for a single pavement rehabilitation).

Performance Period Economic Analysis

The traditional LCCA is performed to make decisions for pavement type selection, and long-term pavement strategies. However, there are few new alignments being designed and built today, and reconstruction is infrequent because of a concerted effort at WSDOT to preserve the pavement structure and avoid reconstruction.

A far more common situation is the year-to-year decisions that are made regarding the maintenance and resurfacing treatments for a given section of roadway. These decisions are made based on the conditions in a specific performance period. The rate of pavement deterioration, the maintenance treatments appropriate for the pavement condition, the timing of the eventual rehabilitation, the costs incurred, are all part of a single performance period evaluation.

Decisions on when and how to resurface a pavement at the end of a performance period is the most common pavement management decision made. WSDOT has about 18,500 roadway lane-miles (29,600 lane-km), where 100 – 200 resurfacing projects are evaluated every year for asphalt and chip seal pavements. A previous analysis *(4)* of what effect one year difference in time of resurfacing makes is shown in Figure 1. As the life of a pavement performance period grows, the annual costs drop. Figure 1 illustrates that a one year change in the year of resurfacing can make a 14% - 20% difference in project cost for chip seals (BST), and 4% - 8% difference for asphalt pavements. With resurfacing needs of $150 - $200 million per year for the flexible pavement system, one year differences at the project level can add up to savings of tens of millions of dollars each year, regardless of the assumed discount rate.

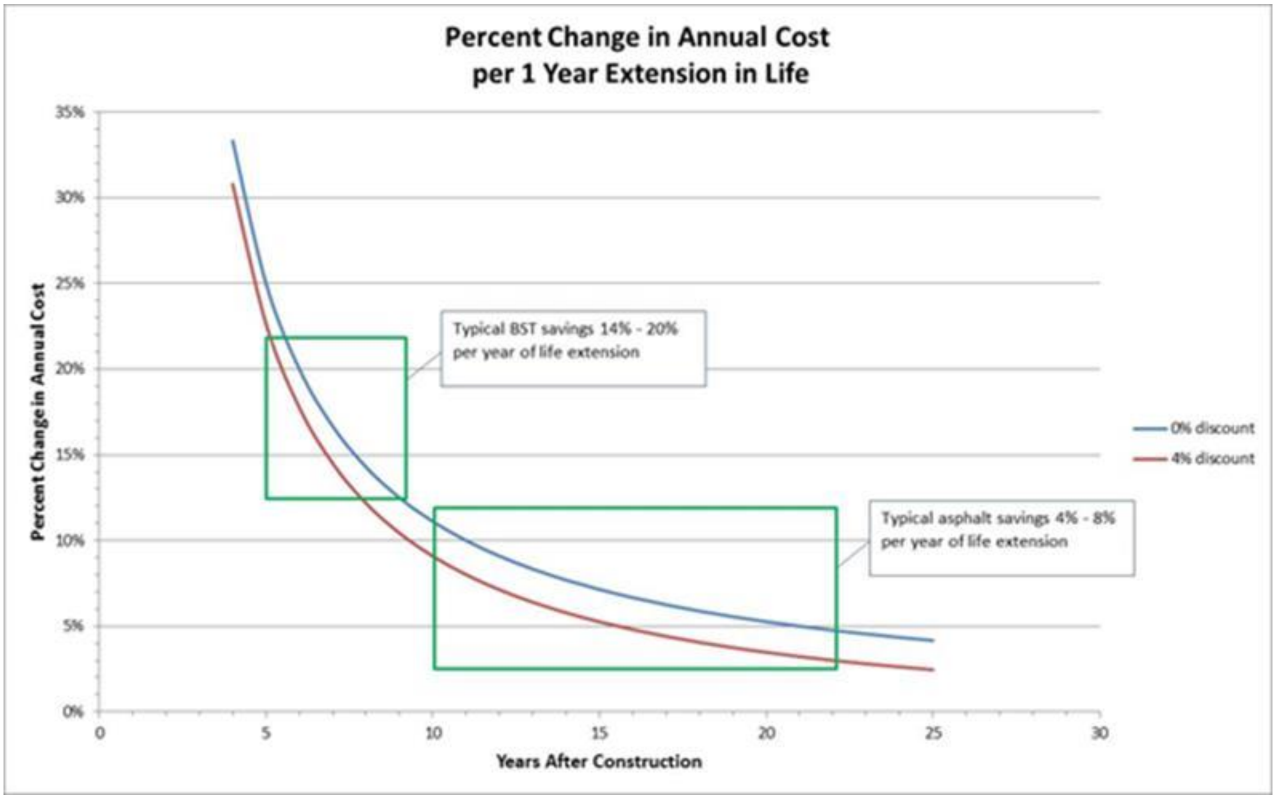

Figure 1. Change in annual cost resulting from one year extension in pavement life.

The evaluation of the economics of pavement management decisions becomes a valuable tool in answering these questions:

- How much has it cost to deliver pavement functionality on the road network?
- What are the most cost-effective pavement management practices?
- Has the investment in the pavement infrastructure been adequate for long term sustainability?
- How well are the pavement assets being managed?

Having answers to these questions is essential for pavement asset management. The cost will obviously be a factor dependent on site conditions and traffic, but for any set of site conditions an agency should have a method for tracking the cost-effectiveness of the pavement management decisions. Perhaps too much is being spent at one location, when those scarce funds could be better spent on a different project. Or, perhaps the road is under-designed and is requiring frequent maintenance, whereas a more cost-effective solution would be to invest in a structural improvement that meets the traffic load requirements. Best management practices for pavement assets require monitoring both pavement functional performance and pavement economics.

COST-EFFECTIVENESS

Infrastructure projects in the public sector are typically analyzed through benefit-cost analysis or cost-effectiveness analysis. A directive of the US Government Office of Management and Budget (OMB) states "*Benefit-cost analysis* is recommended as the technique to use in a formal economic analysis of government programs or projects. *Cost-effectiveness analysis* is a less comprehensive technique, but it can be appropriate when the benefits from competing alternatives are the same or where a policy decision has been made that the benefits must be provided" *(5)*. The fact that benefits of pavement performance are difficult to quantify, and that WSDOT policy is to provide a minimum LOS at the lowest cost, the use of a cost-effectiveness performance measure is appropriate.

Traditional LCCA can be expressed in terms of Net Present Value (NPV) or Equivalent Uniform Annual Cost (EUAC),

$$\text{EUAC} = P\frac{i(1+i)^n}{(1+i)^n - 1}$$

where
P = Present Value of all costs
i = Discount Rate
n = number of years

When evaluating cost-effectiveness there are significant advantages to characterize the life-cycle costs in terms of EUAC rather than NPV. The NPV expresses the total cost only, but the EUAC relates cost to a period of time, which is very useful for expressing cost-effectiveness. For example,

- the EUAC is a simple number that can be directly compared with the annual cost of a different project, or with average annual costs statewide,
- the EUAC is easier to calculate, since the time periods comparing alternatives can be different (no need to use multiple performance periods to compare exactly the same number of years like NPV), and
- when using EUAC there is no need to consider Salvage Value. In practice pavements are not salvaged at the end of service life, but are typically rehabilitated for a new performance period.

The key performance measure for cost-effectiveness in WSDOT pavement management is total cost per lane-mile per year ($/lane-mile/year, or $/LMY), which further normalizes the EUAC by lane-miles. Similar measures have been found appropriate by other researchers to evaluate cost-effectiveness *(6,7)*. This parameter is an excellent "common denominator" that can be used to compare pavement strategies with different construction costs, different performance lives, different maintenance treatments, and different paving lengths. Table 1 shows typical cost-effectiveness numbers for different WSDOT pavements. These numbers are typical of statewide trends, but can vary substantially under different project conditions.

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

Table 1. Typical annual costs for different types of WSDOT pavement treatments.

Costs in Table 1 include all items related to pavement rehabilitation: engineering, mobilization, construction traffic control, and paving, but exclude non-pavement items such as culverts, signals, guardrail, etc. that may be part of the same project.

Cost-effectiveness is expressed in terms of dollars per lane-mile, per year ($/LMY). Since pavement structures are designed primarily on the basis of truck loading, a similar term can be used expressing cost-effectiveness per truck (dollars per truck-mile traveled, and dollars per Equivalent Single Axle Load (ESAL) traveled). WSDOT uses the cost per lane-mile per truck as a key factor when prioritizing pavement rehabilitation projects across the state. In times of tight budgets, cost-effectiveness is an especially significant factor in determining the priority of individual projects.

REPLACEMENT ANALYSIS

Replacement Analysis is a method commonly used in Industrial Engineering to evaluate the optimal time to replace equipment or machinery. The method analyzes costs using EUAC to determine the year at which the total annual costs of buying, operating, and maintaining equipment are minimized *(8)*. This concept can also be used to evaluate the optimal time to "replace" a pavement surface. Figure 2 illustrates an example of an asphalt surface that is constructed at a cost of $250,000 per lane-mile, and is evaluated over a 20 year performance period. The annual cost of the construction will decrease as the years increase, but over time the maintenance and repair costs will increase and eventually the total annual cost will increase. The point where the total annual costs are minimum is the optimal time to resurface, and is also referred to as the Economic Life.

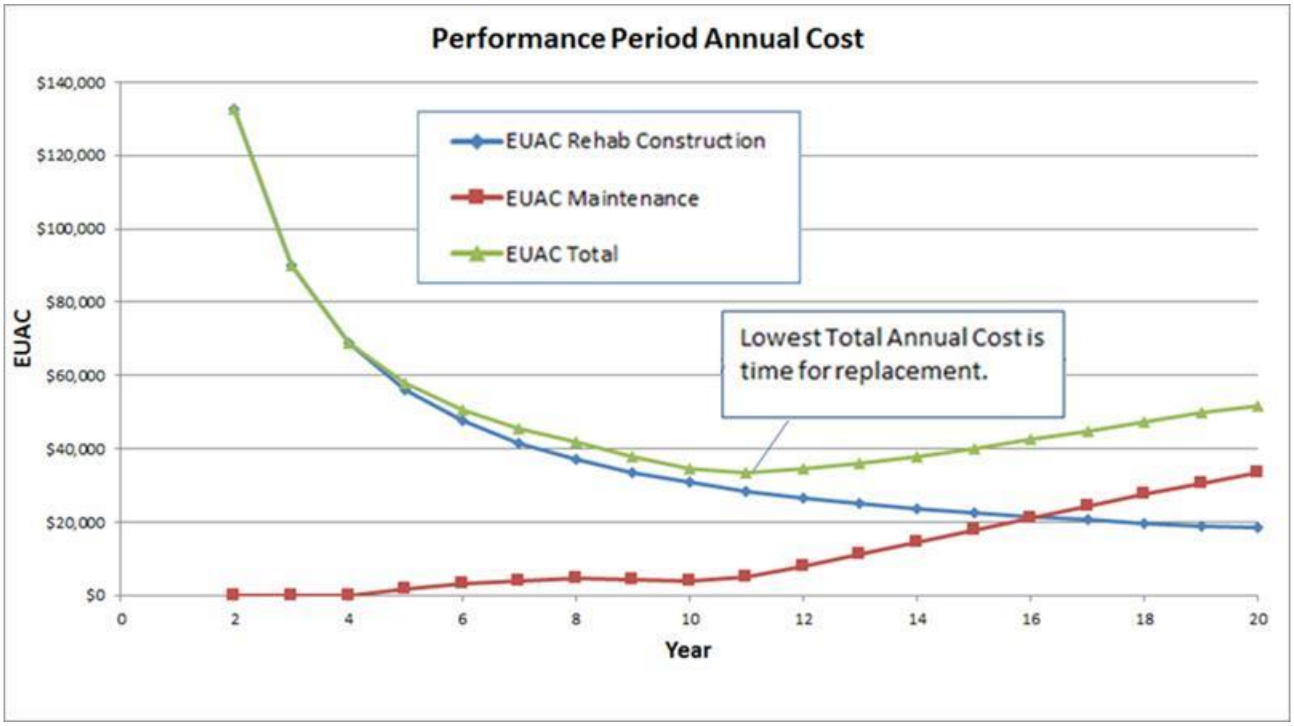

Figure 2 Illustration of Replacement Analysis for pavement performance period.

When the lowest annual cost is reached in a performance period (the Economic Life of that treatment), the engineer needs to consider alternatives, since doing nothing will result in higher future costs. The alternatives could be to do maintenance and extend the life a few years, or to consider different types of rehabilitation treatments that would start a new performance period. In Replacement Analysis, any of these alternatives can be considered, but the main criterion is that the expected annual cost of a selected alternative must be less than the current annual cost (if not, then there is no better alternative than doing nothing until a better alternative is available).

One of the simplest ways to reduce annual cost is to extend the life of the performance period. To extend pavement life it will be necessary to invest in a preservation treatment in order to maintain satisfactory pavement performance (LOS) and maintain the integrity of the existing pavement structure.

The calculation to evaluate the tradeoff in preservation funds simply sums all expected costs, and evaluates the annual cost over the total years (including the life extension). As an example, see the cash flow diagrams shown below. Figure 3-a shows the simple calculation of an asphalt resurfacing costing $250,000 (per lane-mile), expressed as an equivalent annual expenditure of $26,638 per year.

Figure 3-b shows how spending $20,000 in maintenance ($5k + $15k) has extended the pavement life from 12 years to 15 years. The total annual cost is now $23,538, a reduction of $3,100 per year over 15 years (a reduction of 12%).

Figure 3-a. Calculation of EUAC for an asphalt pavement resurfacing ($250,000) for 12 year period.

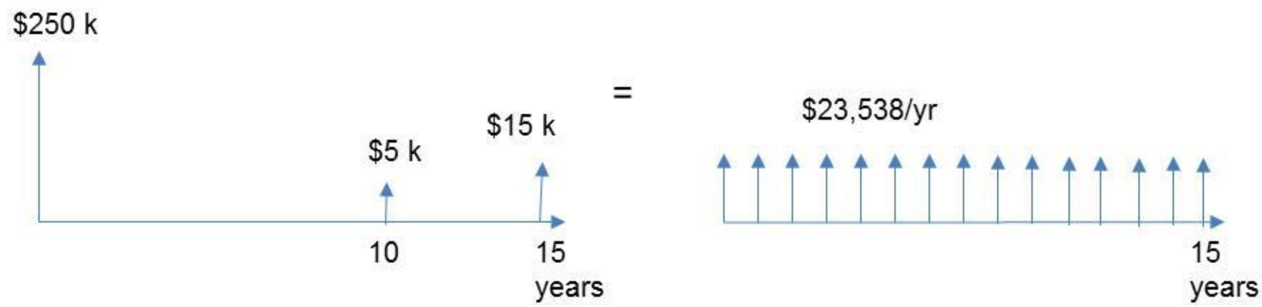

Figure 3-b. Spending additional $5k on maintenance in year 10 and $15k in year 15 and calculating EUAC over 15 years. EUAC is reduced by $3,100 (12%). (Assumed Discount Rate 4%).

BREAK-EVEN ANALYSIS

Continuing with this asphalt preservation example, suppose an agency wanted to determine how much could be spent on maintenance and still break even with the annual cost savings resulting from a 3 year extension in pavement life (from 12 years to 15 years). This tradeoff evaluation is shown in Figure 4. With $250,000 for initial construction, plus $5,000 spent on maintenance, how much additional can be spent in year 13 to still break even with an annual cost of $26,638 per year (the original example in Fig 3a)? This calculation results in an additional $71.2k that can be invested in year 13 to extend pavement life to 15 years and still break even with the baseline annual cost of $26,638.

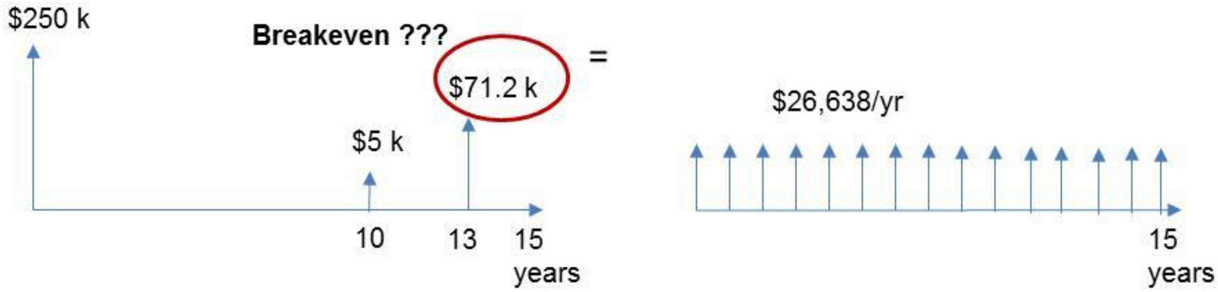

Figure 4. Example of Breakeven Analysis. Spending $5k on maintenance in year 10 and $71.2k in year 13 to achieve a 15 year life is equivalent to EUAC of $26,638/yr. (Assumed Discount Rate 4%).

BUILDING THE DATABASE FOR ECONOMIC PERFORMANCE MEASURES

WSDOT is fortunate to have a robust history of rich data collection throughout the agency, allowing for the Washington State Pavement Management System (WSPMS) to be considered pavement asset management at the proficient and best practice maturity level. A major piece of the economic performance measure puzzle is getting a good estimate for the costs associated with each lane mile within a contract.

Creating the database to calculate the economic performance measures was a substantial task. The ideal data set for analyzing the economics of each construction contract would have a “paving cost” associated to each layer and segment for a given contract. The “paving cost” of a contract would ignore those costs of a contract not directly associated to the production of a particular layer, such as structures and safety costs. Therefore the “paving cost” would be those items of a contract that are universally applied to paving contracts, regardless of the unique circumstances present individually. Unfortunately, no such data set exists at WSDOT. However, there is an itemized cost database by Contract Number. In conjunction with Contract Location data (which includes route location, material type and thickness of each layer) for each Contract Number, an approximation of this ideal data set was created.

This is accomplished by first categorizing each item within the Contract Item database into the following general categories: Paving, Traffic Control, Mobilization, Safety, Structure, Grading, and Other. An automated process was developed that looks at existing fields within the itemized database: Standard Item Number, Construction Work Category and Item Description. Easier items to categorize are already categorized by Standard Item Number or Construction Work Category, since the purpose of these columns is to aggregate items. The more difficult items to categorize are the ones where there is no Standard Item Number or Construction Work Category associated with it. In that case the Item Description is parsed for keyword phrases for categorization.

After each item was categorized, the summation of each category was produced by Contract Number. When combined with information from the Contract Location data, a General Paving Dollars/Lane Mile can be produced for each contract. The General Paving Dollars is the total of the Paving, Traffic Control and Mobilization categories, since these categories are applicable to all paving projects.

Calculating lane miles for a given contract comes with its own difficulties since the Contract Location data does not have actual lane miles paved at the time of the contract work. It has the limits, types of work, and may indicate if the work was done only in specific lanes. If there is no indication of the work being done in specific lanes, then the work applies to all lanes at the time of construction. Therefore, to properly calculate lane miles for a given contract, two things must be considered. First, the contract must be checked to see if the work applies only to specific lanes. Second, contract work occurring after the contract being analyzed must be considered to check if lanes are added or removed. For example, if a future contract adds a lane, this means that previous contracts were not applied to the newer lane, and this must be accounted for when analyzing cost per lane mile.

EVALUATING COST-EFFECTIVENESS BY LOCATION

The implementation of cost-effectiveness measures is accomplished through the WSPMS. For any section of road the $/LMY and $/ESAL can be displayed. Looking at the variation in costs for different locations along a route can be very useful in evaluating pavement management decisions and finding locations of high cost that may need remedies.

Figure 5 shows a screen print from WSPMS for an example section of roadway. Seeing that the $/LMY changes at a specific location can be used to examine this segment of road further. In this particular example the road surface type changes from chip seal to asphalt, which increased the cost of pavement structure. In addition, the performance at this location was poor due to difficulties with underlying site conditions (which required some pavement structure rebuilding, and more costs). Other examples where noticeable increases in costs occur are for urban areas, where costs of traffic control and construction often make the total cost higher.

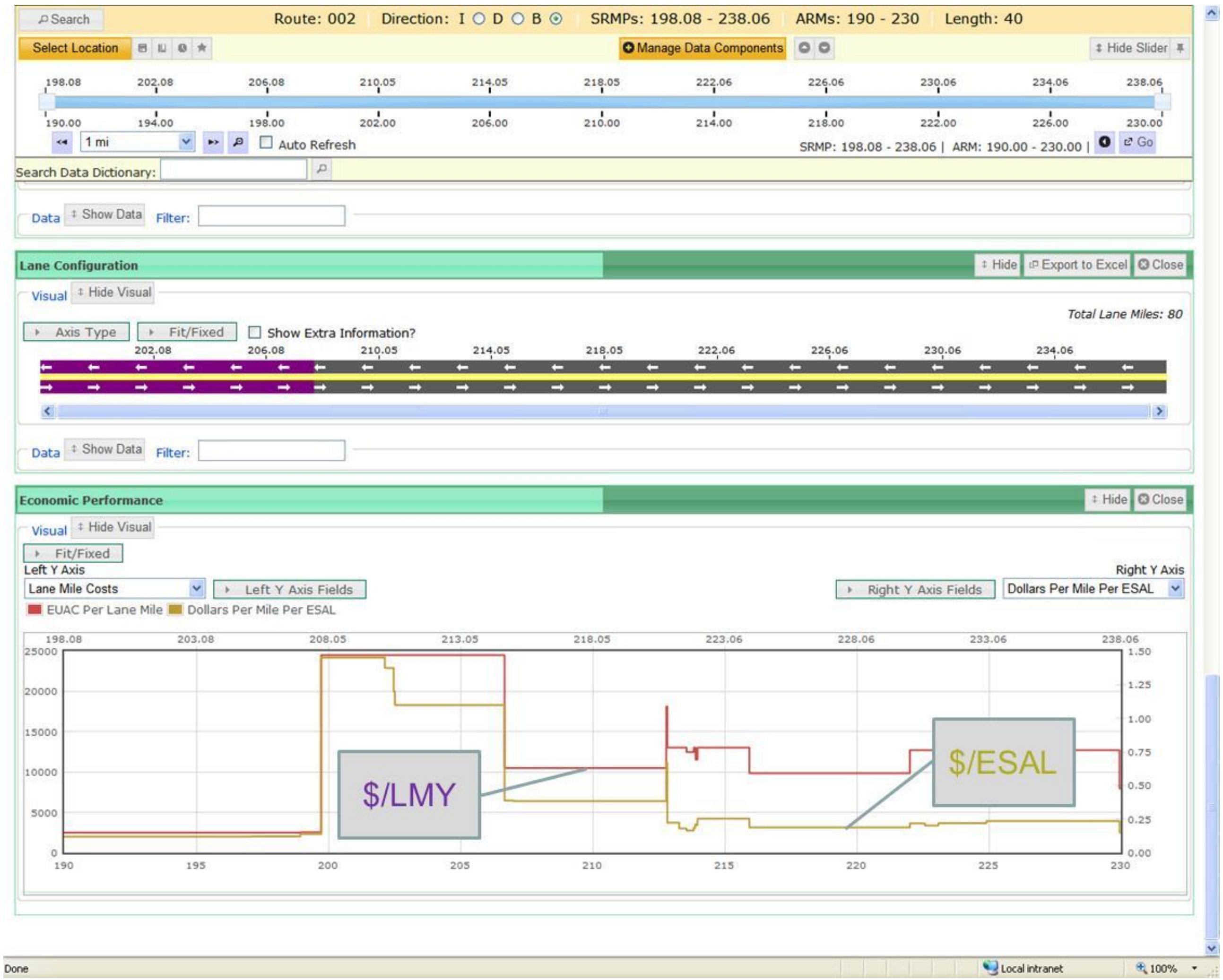

Figure 5. Example WSPMS screen diagram showing $/LMY and $/ESAL along a route.

Using the $/LMY plot from WSPMS can also be used to scan a route for locations where historical costs may be high. Figure 6 shows another screen diagram from WSPMS where a particular section of road shows much higher $/LMY. Looking at the diagram of construction history (that is immediately below the cost-effectiveness diagram), it shows that multiple rehabilitations have occurred at this location over a short period of time (three overlays in six years). Examining the background of this location further let to the discovery that this section of road is situated on an unstable side slope, which was the reason for the excessive amount of work on this short section of road. Each time the slope moved slightly, the road needed to be re-profiled. In this case the costs of continued rehabilitation can be evaluated in comparison with the costs of stabilizing (or mitigating) the long-term effects of the unstable slope.

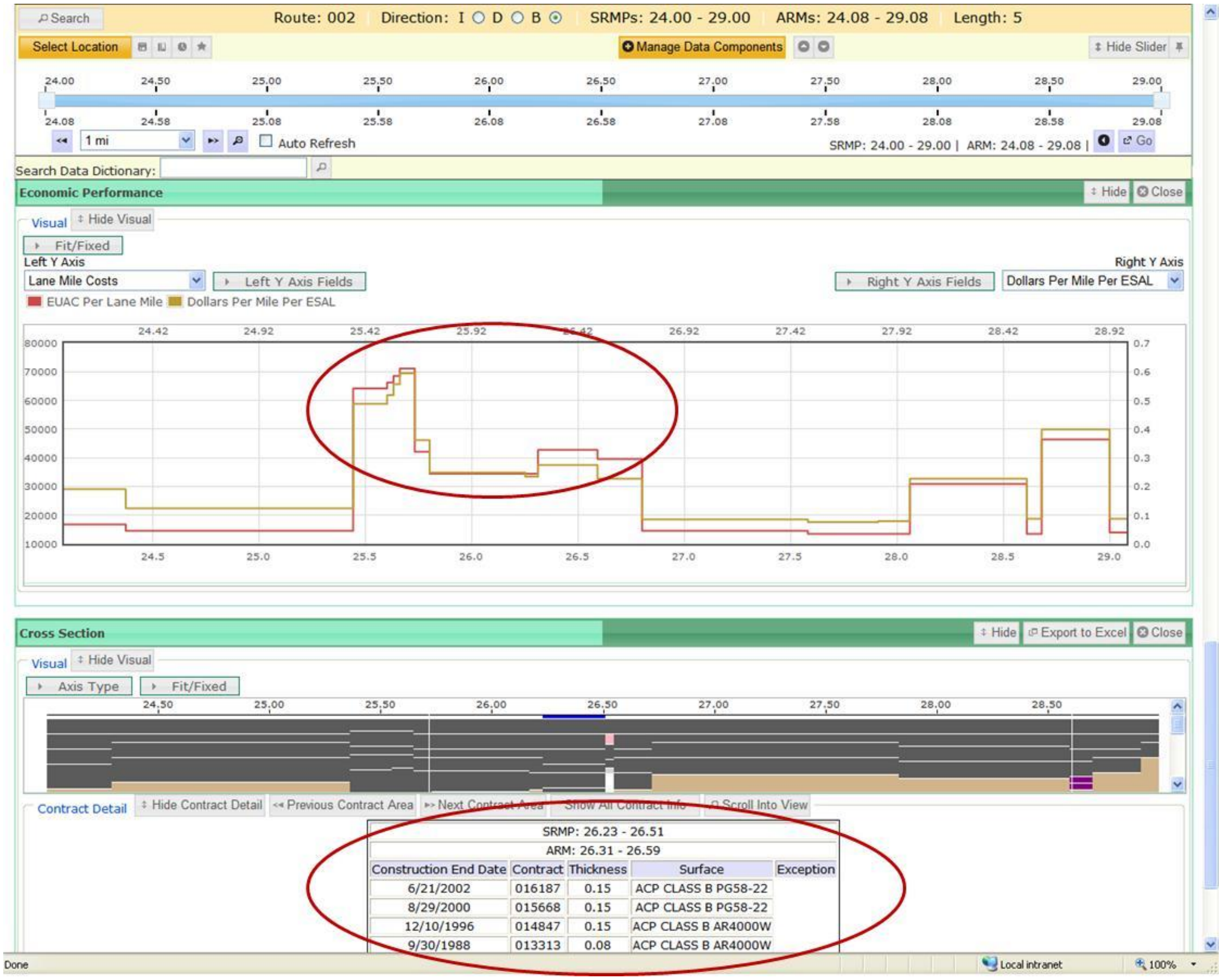

Figure 6. WSPMS screen diagram showing location of high cost caused by repeated overlays.

PROJECT EVALUATION

As the cost-effectiveness data is examined in more detail, it is apparent that it can be very useful in examining the performance of individual contracts. Figure 7 shows an example of this application. After several years of pavement performance the next Due Year for rehabilitation can be estimated, and the contract can be evaluated if it is performing as planned, or is under performing.

The small triangles in Figure 7 indicate the number of lane-miles in the data, and some spikes in $/LMY may occur with very small data sets and these specific data can be filtered out. Contracts with very high costs are flagged for further investigation. Sometimes these high $/LMY costs are due to poor construction (problems with the asphalt mix, paving too late in the season, etc.) which lead to shorter pavement life. This provides the ability to not only "remember" the causes of poor performance and try to use that experience to improve future practices, but it also allows the calculation of how much money was lost due to poor decision making or poor construction.

In the same respect, much can be learned from successes, when pavements last longer than originally planned, or new procedures or materials are used which reduce cost and lead to more cost-effective performance. Learning from these successes, and quantifying the savings, can assist in implementing good pavement asset management practices statewide.

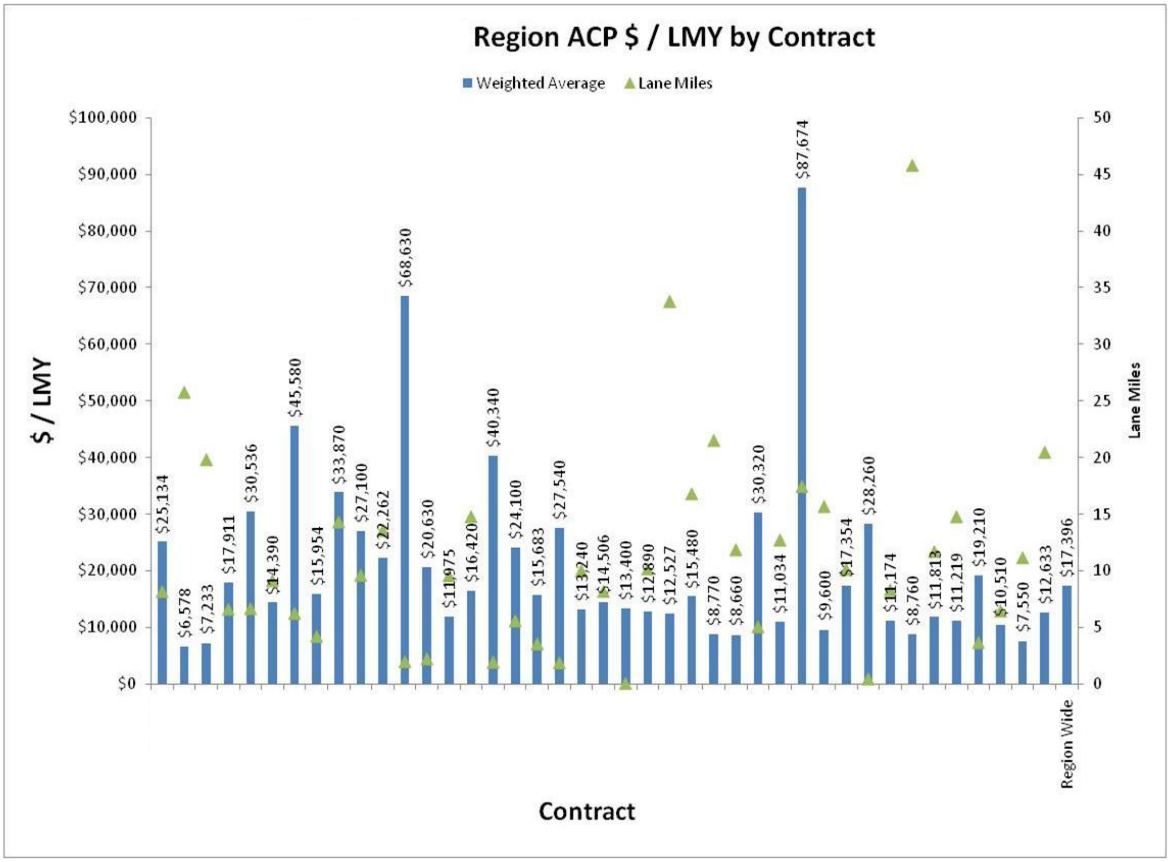

Figure 7. $/LMY calculated by contract.

CONCLUSION

The use of economic performance measures is essential to good pavement management practices. The use of traditional LCCA is important in selecting pavement strategies regarding new or reconstructed pavements. However, a far more common pavement management decision is the year-to-year evaluation of rehabilitation and preservation treatments for existing pavements.

The use of economic evaluation techniques such as Cost Effectiveness Analysis, Replacement Analysis, and Break-Even Analysis is essential in making pavement management decisions, and can result in substantial cost savings. Even a one-year extension in pavement life through the use of cost-effective pavement treatments can result in substantial benefits when implemented on a network basis.

The management of transportation infrastructure requires the assessment of total costs to deliver and maintain the pavement structures that are carrying freight and the traveling public.

Examples were shown of monitoring cost-effectiveness by location, and evaluating the cost-effectiveness of individual contracts. WSDOT uses cost-effectiveness directly in prioritizing pavement rehabilitation projects statewide. These economic measures provide essential information about how pavement assets are being managed, and can lead to better pavement asset management practices.

DISCLAIMER

This paper contains the opinions and viewpoints of the authors alone, and does not constitute a policy or standard of the Washington State Department of Transportation.

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