Oregon Department of Transportation

INVESTMENT TRADEOFFS USING HERS: Analysis for 1999 Oregon Highway Plan

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Transportation Planning Section
Transportation Development Division, Salem, Oregon

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EXECUTIVE SUMMARY

As the Oregon Department of Transportation faces increased funding constraints accompanied with a greater demand for accountability in expenditures, the Department is using tools to assist in prioritizing needs or deficiencies on the highway system. One such tool is the Highway Economic Requirements System modeling software (HERS).

The Oregon Highway Plan staff recently began to utilize the HERS modeling software to assist in the highway needs analysis for the Oregon state highway system. The HERS model uses benefit-cost analysis (BCA) to compare the intrinsic worth of alternative improvement strategies. The model simulates improvement selection decisions based on the relative benefit-cost merits of alternative improvement options, and then evaluates the long-term capital spending necessary in order to achieve specified future levels of highway performance. In essence, the HERS model implements only those improvements that are economically justified. This analysis provides a solid foundation for budgetary and legislative program development and evaluation, and can be done at either the program or project level.

For this study, the staff used HERS to analyze the highway system condition and performance at the end of a twenty-year analysis period for three scenarios at varying degrees of modernization and preservation improvements. When compared with the existing base condition, this analysis provides a foundation for evaluating tradeoffs in both funding and improvement categories. All data represents 1997 highway conditions and dollars. The analysis includes construction costs but not costs for preliminary engineering, construction engineering and right-of way.

Average effective speed (AES) and user costs per mile (UC) are used to assess the system performance. These measures are tracked during three scenarios at increasing funding constraints, all with a different mixture of preservation and modernization improvements. An initial benchmark, defined as the condition and performance of the system at the beginning of the analysis period, establishes the state average effective speed at about 43 mph and average user cost at about 82¢ per mile (actual values vary by region and road classification).

The first scenario, preservation only (**PRES**), is an attempt to analyze the requirements for maintaining or protecting the existing infrastructure by means of preservation improvements (i.e., zero modernization improvements). This scenario seems to work well in the less congested areas of the state, more generally Central, Southern, and Eastern Oregon, as well as for some areas in the greater Willamette Valley defined with lower roadway classifications (i.e., Regional and District). However, this scenario fails to address the current and future congestion issues that are primarily located in the greater Willamette Valley area, specifically on the Interstate and Statewide systems. As

a result of these unmet congestion issues, the highway system experiences over a one-third decrease (-37%) in state average traveling speed over the twenty-year analysis period, while the average user cost per mile increases by about one-third (+31%) for the same time period. The preservation only scenario results in a state average effective speed of about 27 mph and an average user cost of $1.07 per mile.

This scenario shows that the initial priority for funds should be preservation, since it seems to provide the highest initial rate of return on investment. However, as the investment increases there reaches a point of diminishing return due to the continual increase in congestion. Then this investment scenario becomes ineffective. At this point, some modernization improvements need to be considered. The tradeoff is a higher initial rate of return from preservation dollars at the expense of more congestion.

Moderate levels of modernization improvements are added in the second scenario, region-restricted modernization (**MOD-RR** – the scenario used for the Feasible Needs Scenario in the 1999 Oregon Highway Plan). Many of the congestion issues are addressed using the conservative approach of adding one single lane maximum in each direction, where needed. As a result of the increased capacity, significant improvements are observed in both the state average effective speed and average user cost per mile for most areas of the state, as compared with the preservation scenario. However, this is still not enough to address the congestion problems in the greater Willamette Valley area. The states average speed declines 26% to about 32 mph over the analysis period, while the average user costs increase 17% to $1.02 per mile.

The third scenario contains a strong emphasis on modernization, where increased capacity improvements are allowed at a considerably higher improvement cost (**MOD-HC**). Since all the congestion is addressed in this scenario, the state average effective speed and average user cost per mile are notably improved, as compared with all other scenarios. However, this scenario shows enormous costs associated with the vehicular improvements. The average speed increases to 49 mph (+14%) and the average user costs decrease to 74¢ per mile (-10%).

If the state only has $100 million to invest annually, the best return on investment is to protect the current infrastructure using just preservation improvements. Even at this conservative rate spread out over the twenty-year analysis period, the average speed is 25 mph, the average user cost is $1.13 per mile and the projected pavement condition is 42% FoB. NOTE: Though the pavement deterioration rates used in HERS are not calibrated to those used by ODOT's Pavement Unit, the pavement condition would only vary slightly, and the results would be similar.

Any investment over $100 million per year should include some level of modernization to address the congestion issues. At about the $160 million annual investment level, the state average effective speed and the average user cost per mile are maximized for the preservation scenario, and the modernization element then controls any further performance changes. NOTE: The pavement condition (FoB) still improves at higher preservation investment levels, however, congestion drastically effects the performance.

Clearly, the decision of improvement type, location and investment amount (what, when, where, and how) will directly affect the state average speed and user cost per mile.

The HERS model implements only those improvements that are economically justified. ODOT may fund highway improvements that would not pass the same economic test, but may have other equally valuable considerations.

The Oregon Transportation Commission will be making tough investment decisions. Their decisions will determine which areas should be modernized and what types of improvements should be made. Though the HERS analysis helps present a clear picture of the condition of the highway system under different funding scenarios and time frames, it is only one piece of the total transportation puzzle. There are additional improvements that cannot be adequately simulated by HERS (i.e., intersection and interchange improvements), while other program needs, as defined in OHP (i.e., bridge, maintenance, safety, and operations), fall outside the modeling parameters. Additional analysis is used by ODOT to evaluate those system needs.

Still, HERS is one way to establish supportive economical analysis, since the model effectively utilizes benefit-cost analysis as a foundation for determining the best combination of improvements within a program or project, and for allocating resources between programs.

INTRODUCTION

In developing the 1999 Oregon Highway Plan, the staff needed to evaluate investment tradeoffs between preservation and modernization improvements. The staff used the Highway Economic Requirements System (HERS) model to investigate the effects on the overall vehicular performance on the Oregon state highway system of varying degrees of modernization and preservation improvements. This study was conducted using a wide program level scope, as opposed to the more specific project level bases.

HERS allowed ODOT's to evaluate investment tradeoffs using defined performance goals. The performance goals provided a future snapshot of the highway system by roadway classification (SCS), as anticipated at the end of the twenty-year analysis period.

A dataset was developed for OHP, representing the entire Oregon state highway system. Input user parameters were adjusted to match the required scenarios. The data was run through the model and the output analyzed for this study.

HERS initiated the analysis process by evaluating the current state of the highway system, assessing both the condition and performance for each section at the beginning of the analysis period. Using traffic growth projections that are section-specific, the model forecast future conditions and performance for each funding period, and identified system

deficiencies. Deficient sections were further analyzed with engineering standards to identify and list potential improvements. Economic criteria were applied to the analysis in order to select the best improvements; user and agency benefits and costs associated with potential improvements were simulated and used to evaluate the relative merits of the improvements according to generated net benefits. Improvements were selected and the required capital investment was estimated until the system funding constraints or user cost objectives were satisfied (i.e., until the problem was fixed or the money run out, whichever came first). The future performance was evaluated for the ending of each funding period. The HERS model implemented only those improvements that were economically justified, based on a comparison of the construction costs and the lifetime benefits for each improvement.

The overall analysis process used in this study appears to be reasonable and should prove to be a valuable technical resource, providing sound documented support for future investment decisions.

HISTORY

The Oregon Department of Transportation (ODOT) has made extensive use of the Highway Performance Monitoring System Analytical Process (HPMSAP or AP) modeling software for planning analysis. Most recently, Oregon used the AP model to provide supporting data for Corridor Plans (1993-1996), the Roads Finance Study (1992-1993), the Oregon Transportation Initiative (1996), and the Oregon Highway Plan (1997-1999).

During the data analysis process for the 1999 Oregon Highway Plan (OHP), the Planning Section began using the Highway Economic Requirements System (HERS) modeling software. HERS was developed for the Federal Highway Administration (FHWA) by Cambridge Systematics staff as an analysis tool that could maximize the use of limited public resources. The model simulates improvements based on the relative benefit-cost merits of alternative improvement options.

The HERS and AP are similar analytical models based on using engineering standards to identify roadway deficiencies. They differ in that the AP identifies needed improvements to the physical conditions and performance of the highway based on engineering standards only, while HERS uses economic criteria along with engineering standards to select improvements that minimize the required system investments. This dimension becomes more important as public resources become increasingly constrained. Both software models are supported on a national basis by FHWA.

To facilitate the data analysis required for OHP, Cambridge Systematics customized several significant HERS features for Oregon. The most sweeping enhancement was the added feature that allows the user to override the model's simulated improvements. The

user has the ability to revise the model's dataset so that the simulated improvements reflect "real world" conditions (i.e., anticipated changes in traffic volumes based on known land use changes, adjustments for geometric or environmental restrictions, etc).

For example, on one particular roadway section the HERS analysis showed that the most economical improvement for dealing with the growing congestion was the construction of additional lanes. However, while developing the local transportation system plan, the local planners concluded that the best solution was simply to widen the shoulders and live with the congestion. The HERS dataset was then adjusted to reflect the local improvement needs. However, the system performance still continued to deteriorate due to the unmet congestion needs.

NOTE: Both HERS and AP use sectional analysis where the needs of individual sections are evaluated independently of adjacent sections. Network analysis is not incorporated, and mode shifting is not considered.

DEFINITIONS

Average Effective Speed (AES) is the modified unconstrained average speed that exists for a highway section. It is the maximum speed allowed given terrain type, grade, curvature, number of heavy trucks, facility type, number of lanes, speed limit, volume-to-capacity (VC) ratio, pavement roughness, speed limit enforcement, safety concerns and congestion, as modified by the effects of speed-changes and stop cycles (including idling time associated with these effects).

The ***User Cost per Mile*** is composed primarily of three specific elements in the HERS analysis: 1) operating costs (including insurance, gas and maintenance on the vehicle), 2) travel costs (including driver's time), and 3) crash costs based on the number of crashs that would be expected, with or without the improvements. For this study, all costs are based on national trends.

The ***vehicle operating costs*** are the costs of operating a vehicle on a given section, reflected by costs of fuel, oil, tires, maintenance and repair, and mileage-related depreciation. The average grade, pavement condition, speed-change and stop cycles, and curvature affect these costs for each vehicle type.

The ***travel time costs*** are split between commercial trips (work-related) and non-commercial trips (non-work and commuting). The commercial trips ("on-the-clock") are valued on the basis of savings to the employer, including wages, fringe benefits, vehicle cost and inventory (cargo) carrying costs. The non-commercial trips ("off-the-clock") are defined as trips for commuting, personal business, and leisure activities. All costs are based on national statistics and vary by vehicle type.

The ***safety costs*** for each section are developed by determining the specific incident rates (i.e., the expected annual number of crashes, injuries and fatalities), multiplied by a cost per incident (including crash costs, injury costs and value of life), and then summing all incident cost components. The incident rate varies by facility type, traffic volumes, and estimated value of safety benefits for improvements (i.e., adding lanes, restricting access, and/or adding a median). All costs (including value of life) are based on national statistics and vary by vehicle type.

Total Annual User Costs are the calculated annual user costs, based on 1997 dollars ($1997). They are determined by multiplying the user cost per mile by the number of annual vehicle miles traveled (VMT).

Vehicle Miles Traveled (VMT) is the annual number of daily vehicle miles of travel. It is derived by multiplying the Average Annual Daily Traffic (AADT) with the section length and 365 days.

Fair-or-Better (FoB) Pavement Condition is the rating system used by the ODOT Pavement Unit to evaluate the overall condition of the roadway system. The pavement condition for each roadway section is given a rating from Very Good (#1) to Very Poor (#5). The overall system is then analyzed according to the ratings. The average pavement condition of state highways in 1997 was 77% FoB.

Statewide Highway Classification System (SCS) is a system for categorizing state highways on the Oregon State Highway System according to their regional function, as defined in the OHP. The purpose being to aid in the planning, management, and investment decisions regarding state highway facilities. The roadway sections fit into one of four classifications (i.e., Interstate, Statewide, Regional, or District). This should not be confused with the National Highway System (NHS) or the Functional Classification System.

THE PROCESS

NOTE: The information documented in this report only reflects general trends. A more detailed analytical process is required to apply this type of data to specific Oregon conditions (i.e., pavement deterioration and crash rates).

The HERS model used a twenty-year analysis period, split into four equal five-year funding periods (i.e., 1998-2002, 2003-2007, 2008-2012, and 2013-2017. The modeled output was used to compare the "now" and "then" condition and performance of the system, defined as the conditions at the beginning of the analysis period (i.e., existing or current conditions, defined as 1997) and the conditions at the end of the fourth funding period (2017).

Three different scenarios were analyzed: 1) Preservation Only Scenario (**PRES)**, 2) Moderate Preservation and Modernization Scenario (**MOD-RR)**, and 3) Ambitious Preservation and Modernization Scenario (**MOD-HC)**. The performance range for each scenario was evaluated by running the two extreme funding levels (i.e., no funding and unlimited funding). Once the two extremes were defined, subsequent multiple runs (beginning with the lower extreme) were made by incrementally increasing the funding levels by $10 million per year until the maximum performance was achieved, as defined by the scenario. The **ZERO** funding level used an unrealistic assumption that no improvements would be allowed during the twenty-year analysis period (similar to the state's going bankrupt). The unlimited funding level was equally unrealistic, assuming that all improvements would be made, as defined by the scenario. Each incremental series was run six times, once for the state average, and once for each of the five regions. As a by-product, each series was further disaggregated by the Statewide Highway Classification System (SCS), as defined in the OHP (i.e., Interstate, Statewide, Regional, and District).

The ***Benefit-Cost Ratio (BCR)*** is the triggering threshold at which improvements are accepted. In a real world situation the BCR would be set at the very least to 1.0, and very likely to 3.0 or more, depending of the desired economic rate of return for the investment. A higher BCR standard results in fewer improvements being accepted and implemented by the model, resulting in lower total needs, lower average speeds (AES), and higher average user costs. For this study, the BCR was lowered to 0.2 to better define the curvature for the speed and user cost curves (Chart 1 & 2), at the lower funding constraints.

SCENARIOS

In addition to the three defined scenarios, two special cases are recognized as being critical points to facilitate comparisons and discussions. The first is the **EXISTING** condition, which defines the year that the data was collected (1997), and represents the current condition of the system at the beginning of the analysis period. This data provides an important picture of what the system looks like today.

The second is the **ZERO** funding condition, which defines the condition of the system at the end of the fourth funding period when no funding has been expended on the system, and consequently no improvements are allowed. Though unrealistic, this detail provides a valuable picture of what the system would look like in 20 years without any work. It is also known as the worst case scenario.

Preservation Only

The **PRES** scenario simulates only preservation type improvements; preservation is defined as pavement reconstruction and resurfacing improvements. This scenario reflects the "pave only" condition, as recently outlined by ODOT's Pavement Unit, where only the existing pavement ("black-on-black") is replaced or improved. Modernization improvements, including minor safety upgrades such as shoulder widening, are not allowed. This scenario is similar to the "preservation only" condition proposed by the Governor and the 1996 Oregon Transportation Initiative. In this scenario, system capacity is not improved.

Preservation and Modernization Scenario with Region Restricted Improvements

The **MOD-RR** scenario moderately simulates both preservation and modernization improvements. This dataset was developed for the OHP, where all improvements were region restricted (**RR**), or based on comments obtained during the region review process. The modernization improvements reflect feasible needs based on local system plans and/or input from professional region personnel, as documented in the OHP. Widening of the system is limited to one additional lane in each direction, unless instructed otherwise by regional staff. The preservation improvements are based on the 90% Fair-or-Better (FoB) database, provided by the Pavement Management System (PMS) model. The PMS database defines what pavement improvements are needed to increase the 77% FoB condition in 1997 to the 90% FoB by 2010, and then to maintain that condition level until 2017. The improvement unit costs were derived for the 1993 Roads Finance Study and adjusted to reflect 1997 dollars ($1997). In this scenario, some congestion problems are addressed.

Preservation and Modernization Scenario with High Cost Improvements

The **MOD-HC** scenario is an ambitious and unrestrained analysis, in which the model is empowered to select all required modernization and preservation improvements. No restrictions are imposed during the analysis. Using Interstate 5 in Portland as an example, the model simulates additional lane improvements based on the current and/or projected congestion, usually adding eight to ten lanes in each direction. For this scenario, all additional lanes, beyond the initial lane limits in **MOD-RR**, are simulated at a higher cost (**HC**). For the purpose of this analysis, the higher cost is arbitrarily defined as four times the normal cost and can best be described as the anticipated cost of building a new roadway parallel to the existing system.

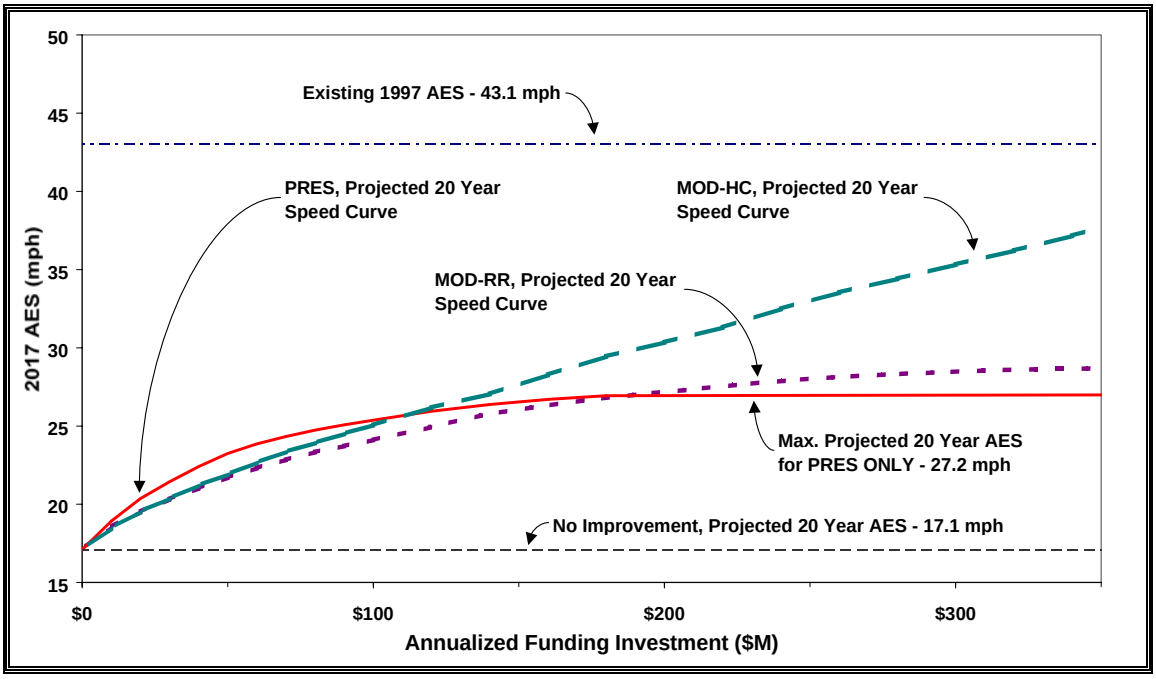
Building such a facility would not be realistic either financially or politically, but is used here to illustrate what would be required to maintain or improve mobility by automobile in some of the more congested areas**.** In this scenario, all congestion problems are addressed.

INDIVIDUAL RESULTS

For each scenario, the following two categories are tracked: 1) Average Effective Speed (AES), and 2) User Cost per Mile. The Total Annual User Costs were also evaluated, but these costs are just a function of the User Cost per Mile and VMT. The impact of each scenario is illustrated below.

In Chart 1, the projected twenty-year statewide average speed (AES_{2017}) is graphed against increasing funding levels. This chart demonstrates the gap between the existing average speed (AES_{1997} = 43.1 mph) and the future average speed for various funding levels. For example, for an annual expenditure of $100 million per year, the average future speed for the entire state would be approximately 25 mph (**PRES** curve). For this funding stream, the difference (gap) is about 18 mph below AES_{1997}, representing an approximate reduction in speed of 42%. Assuming that no work is done to improve congestion, including mode shifting, the anticipated increase in traffic would add about one minute of travel time to each mile traveled (statewide average).

Chart 1: Oregon Statewide Average Effective Speed Curves in 2017, BCR = 0.2



This graph demonstrates how increased funding levels contribute directly to the improved system speeds. However, there comes a point along each curve at which the maximum benefit is achieved for the specific funding scenario. The curves flatten out and remain so, regardless of increased funding, reflecting the point where the effects of increased congestion outweigh the effects of increased funding. Further improvements to the system are only accomplished by jumping to the next higher funding path (i.e., from **PRES** to **MOD-RR**), where increased benefits are derived at greater investment requirements. NOTE: A tremendous variation in speed curves exists between regions and roadway classifications (SCS).

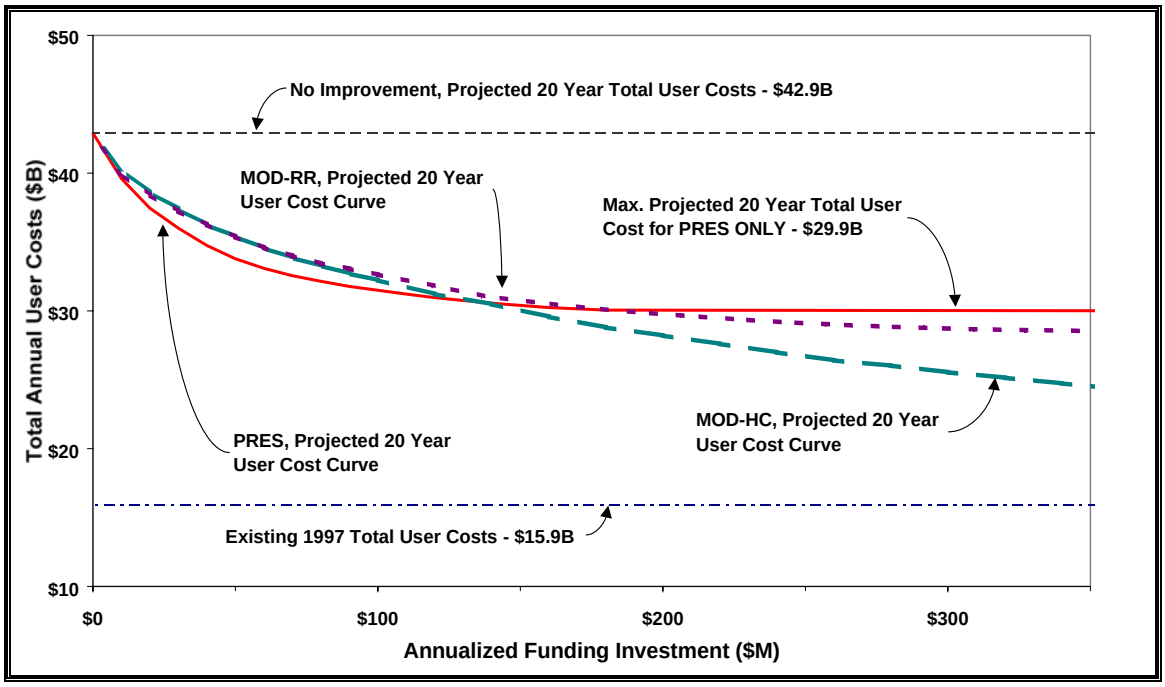
As an example, under the **PRES** scenario the maximum AES_{2017} is 27.2 mph at an investment level of about $220 million per year. Though additional funding would improve the pavement condition, it would have no effect on the average speed, which is heavily influenced by the increased congestion. The model assumes that peak spreading occurs, so the increased congestion simply equates to more hours of congestion. Congestion problems are not addressed until the modernization element is added into the mix (i.e., **MOD-RR** or **MOD-HC**).

For the **MOD-RR** scenario, the maximum AES_{2017} is 28.7 mph, at an investment of about $360 million per year. Though some congestion problems are addressed, clearly not enough is being done to maintain the "steady state" speed condition, where AES_{1997} =

AES_{2017} = 43.1 mph. The maximum AES_{2017} for the **MOD-HC** scenario is 48.9 mph, at an investment of about $875 million per year, well beyond the realm of possibilities.

The Total Annual User Costs are illustrated in Chart 2, again graphed against increasing funding levels. As would be expected, increased improvements to the system result in decreased user costs.

Chart 2: Oregon Statewide Total Annual User Costs Curves in 2017, BCR = 0.2



In the 1999-2003 STIP, the annual expenditure of both the Modernization and Preservation categories combined is approximately $178 million per year ($54 million for modernization and $124 million for preservation). Using Chart 1 and 2, AES_{2017} is estimated to be about 27 mph, at a total annual user cost of approximately $30 billion per year, depending on the funding level (i.e., **PRES**, **MOD-RR** and **MOD-HC**).

Existing 1997 Condition

The existing, or current, 1997 speeds and user costs are the benchmarks for the purpose of comparing all future scenario conditions. For the entire state highway system, the existing average speed is estimated to be 43.1 mph, the average user cost is 82¢ per mile, and the average total annual user costs are $15.9 billion ($1997). These values are identical to those found in OHP, "Table 9: Implications of scenarios for the transportation system."

Table 1a: EXISTING (1997) - AES_{1997} (MPH), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	***43.9***	***32.6***	46.4	***24.8***	**35.4**
Region 2	59.5	43.1	40.5	41.8	**47.1**
Region 3	63.4	42.1	45.8	36.2	**48.8**
Region 4	63.6	48.4	45.7	50.0	**51.0**
Region 5	66.5	47.5	51.4	45.4	**54.3**
Total System (Average)	**52.8**	**40.1**	**43.0**	**31.9**	**43.1**

Shaded cells are the Areas of Concern tracked throughout this study.

Table 1b: EXISTING (1997) - User Cost (¢/Mile), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	***81¢***	***93¢***	76¢	***107¢***	**89¢**
Region 2	73¢	82¢	82¢	83¢	**79¢**
Region 3	74¢	84¢	76¢	87¢	**79¢**
Region 4	76¢	79¢	80¢	78¢	**79¢**
Region 5	75¢	79¢	75¢	81¢	**77¢**
Total System (Average)	**77¢**	**85¢**	**80¢**	**94¢**	**82¢**

Shaded cells are the Areas of Concern tracked throughout this study.

Table 1c: EXISTING (1997) - Total Annual User Costs ($B), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Sum)
Region 1	$2.7	$2.1	$0.1	$1.2	**$6.1**
Region 2	$1.5	$1.9	$0.7	$0.5	**$4.6**
Region 3	$1.0	$0.7	$0.1	$0.5	**$2.3**
Region 4	$0.3	$1.1	$0.1	$0.1	**$1.6**
Region 5	$0.5	$0.4	$0.1	$0.2	**$1.3**
Total System (Summation)	**$6.1**	**$6.2**	**$1.1**	**$2.5**	**$15.9**

Areas of Concern

In evaluating the speeds and user costs by region for each classification (SCS), this analysis tracks several areas of concern throughout this study (designated by shaded cells - see Table 1a & 1b, above). The three primary areas of concern are all located in Region 1, classified as Interstate, Statewide and District highways.

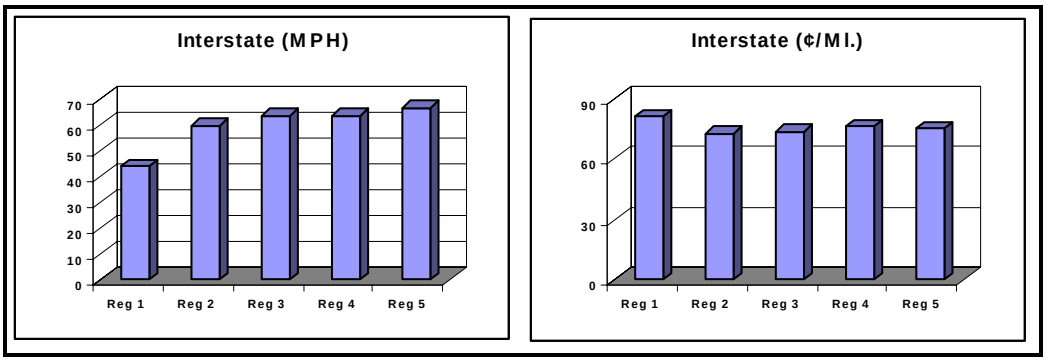
For each area, speeds are noticeably lower than the average for the entire system, and the corresponding user costs per mile are conspicuously higher. The differences can be attributed more or less to congestion, pavement condition, and/or geometric/safety concerns (i.e., terrain, curvature, gradient, lane and shoulder width, etc.). These needs are defined as “backlog” needs, and fall into a category of "existing" or "unmet" needs.

Interstate Classification

The estimated AES_{1997} of 43.9 mph for Region 1 is about 17% below the total state system average of 52.8 mph (≈26-34% below any other specific region). The speeds and user costs for the other four regions are about the same.

Since the Interstate system has the strictest design standards, it is assumed that there are few geometric/safety concerns on the Interstate system, and that the pavement condition is reasonably good. Therefore, the reduction in speed is likely due to congestion. The corresponding user cost is slightly above the state average.

Chart 3a: EXISTING (1997) - Interstate Speed and User Cost, by Region

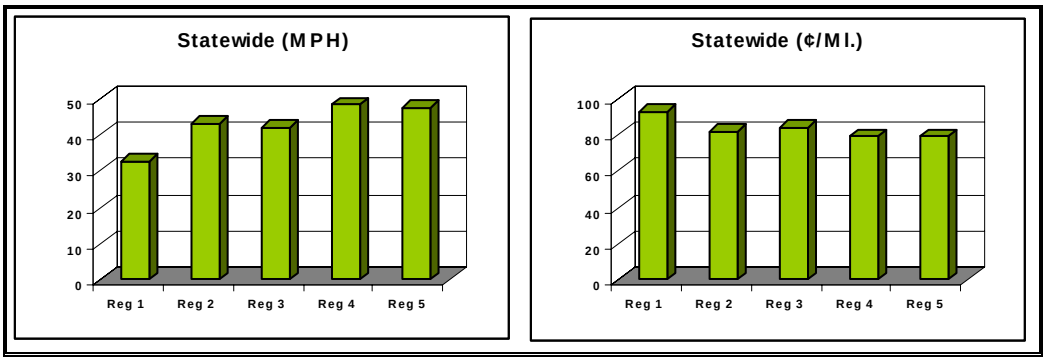


Statewide Classification

The estimated AES_{1997} of 32.6 mph in Region 1 is about 19% below the total state system average of 40.1 mph (≈22-33% below any other specific region). Though the speeds fluctuate slightly for the other four regions, the user costs are about the same.

Based on the design standards, it is assumed that the decreased speed is due primarily to congestion with other possible contributing factors, i.e., pavement condition, and geometric and safety elements. The degree to which each element contributes to the deficit is beyond the scope of this report.

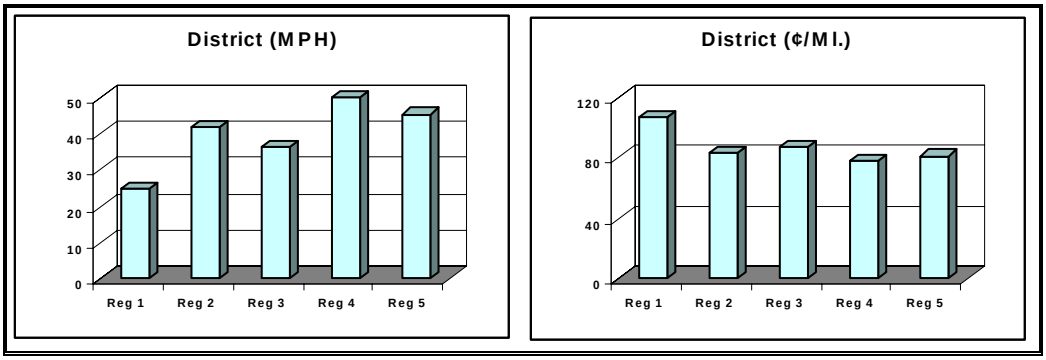
Chart 3b: EXISTING (1997) - Statewide Speed and User Cost, by Region



District Classification

The estimated AES_{1997} of 24.8 mph in Region 1 is about 22% below the total state system average of 31.9 mph (≈31-50% below any other specific region). Based on inconsistent design standards, it is assumed that the decreased speed is due to a combination of many factors, of which congestion is simply one part.

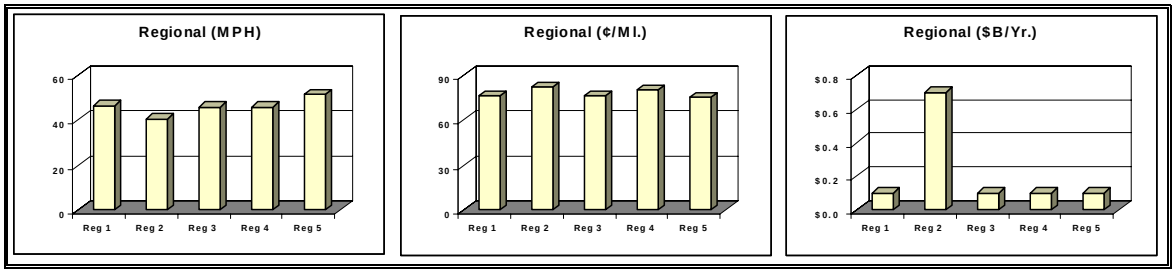
Chart 3c: EXISTING (1997) - District Speed and User Cost, by Region



Regional Classification

At first glance, it appears that the Regional highways in Region 2 should also be tracked, since the total annual user costs (Table 1c) is about seven times higher than that for any other region. However, the estimated AES_{1997} is only about 6% below the total state system average, and the corresponding user cost is about 2.5% above the total average.

Chart 3d: EXISTING (1997) - Regional Speed and User Cost, by Region



The reason for this anomaly is unclear. The VMT for Region 2 (see Table 12a) is about 6.5 times higher for this region than any other. Since the VMT is dependent on both the number of miles classified as Regional and the average annual daily traffic (AADT) that is carried by those roadways, this could indicate some roads classified as Regional are classified as Statewide in other Regions. Though Region 2 only has 27% of the total miles of roadway for this classification (Table 1d), those roads carry 68% of the total average daily traffic for the same classification.

Table 1d: Total Number of Miles* for Each Roadway Classification (SCS), by Region

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	118.68	287.71	39.01	309.10	**754.50**
Region 2	118.58	725.86	269.24	680.01	**1,793.69**
Region 3	168.01	348.72	88.48	395.24	**1,000.45**
Region 4	94.86	910.39	274.05	508.69	**1,787.99**
Region 5	229.92	665.84	473.19	724.93	**2,093.88**
Total System	**730.05**	**2,938.52**	**1,143.97**	**2,617.97**	**7,430.51**

*Rounded Number of Total Miles as identified and used for HERS model.

No Improvement (ZERO)

This "do nothing" condition represents the absolute worst case that would be anticipated at the end of the twenty-year analysis period in 2017. The model was run with zero ($0) funding under the assumption that no work would be done on the system during the analysis period. Though this is an unrealistic expectation, it provides a valuable bottom range for comparing all future conditions.

Table 2a: ZERO (2017) - AES_{1997} (MPH), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	12.2	15.2	28.3	17.5	**13.9**
Region 2	20.6	21.5	18.3	13.2	**19.5**
Region 3	22.0	19.3	25.0	26.4	**21.9**
Region 4	17.4	15.8	15.5	18.3	**16.2**
Region 5	27.3	20.7	23.5	18.7	**23.4**
Total System (Average)	**16.2**	**17.7**	**19.8**	**17.4**	**17.1**

Table 2b: ZERO (2017) - User Cost (¢/Mile), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	192¢	161¢	106¢	145¢	**173¢**
Region 2	139¢	132¢	144¢	187¢	**142¢**
Region 3	140¢	144¢	115¢	111¢	**135¢**
Region 4	171¢	167¢	165¢	149¢	**166¢**
Region 5	127¢	138¢	123¢	146¢	**132¢**
Total System (Average)	**163¢**	**150¢**	**136¢**	**148¢**	**154¢**

Table 2c: ZERO (2017) - Total Annual User Costs ($B), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Sum)
Region 1	$9.9	$5.5	$0.2	$2.2	**$17.8**
Region 2	$4.3	$4.3	$1.6	$1.5	**$11.8**
Region 3	$2.9	$1.7	$0.2	$0.8	**$5.6**
Region 4	$1.0	$3.2	$0.2	$0.3	**$4.8**
Region 5	$1.3	$1.0	$0.3	$0.4	**$2.9**
Total System (Summation)	**$19.5**	**$15.6**	**$2.6**	**$5.3**	**$42.9**

Due to the increased congestion and continued roadway deterioration, the future average speed for the state system drops from 43.1 (at the beginning of the analysis) to 17.1 mph (at the end of the analysis), while the user costs increase from 83¢ to 154¢ per mile (during the same period). The net change in the average speed represents a 60.3% loss of speed on the highway system with a corresponding 87.8% increase in user cost per mile for the same period. The projected total annual user costs for 2017, when factored by VMT, increase from $15.9 billion to $42.9 billion (both in $1997), a 170% (8.5% annualized, uninflated) increase over the twenty-year period.

For this condition, the total annual user costs are increasing at 8.5% per year (annualized, uninflated) over the twenty-year analysis period. The average VMT is growing at about 2.2% per year. When the growth rate for the user costs are normalized with the average VMT growth rate, the average user cost per mile continues to increase by over 6% per year, before adjusting for inflation. Allowing for an average annual inflation rate of 3.3%, as defined in OHP, the estimated current-dollar growth rate per year for the user costs (the cost of each mile of travel) is closer to 9.5%.

Assuming a linear growth in the total annual user costs over the analysis period, the total twenty-year user costs are $588 billion, in 1997 dollars. NOTE: All costs in future year dollars will be much greater when impacted by inflation.

Preservation Only (PRES)

For the **PRES** scenario, only preservation type work is simulated, where preservation improvements are limited to pavement reconstruction and resurfacing (i.e., overlays). Improvements, such as shoulder widening and minor alignment improvements, are classified as preservation-safety (i.e., safety work to be done in conjunction with preservation improvements), and as such, are not included in this analysis.

The goal for this analysis is to simulate pavement improvements for all sections where the pavement condition, as defined by the Present Serviceability Rating (PSR), has deteriorated below minimum tolerable conditions (MTC). The MTCs are triggering points for identifying needs on the highway system. They represent the absolute

minimum that the system is allowed to deteriorate before simulated improvements are required. The pavement deterioration rate used by HERS for this study represents national values and is not calibrated to Oregon standards.

Table 3a: PRES (2017) - AES_{1997} (MPH), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	***15.0***	***17.1***	44.6	***23.3***	**16.7**
Region 2	30.4	41.8	39.4	41.4	**36.4**
Region 3	63.4	41.1	45.9	35.6	**48.7**
Region 4	68.4	47.9	49.1	50.1	**51.3**
Region 5	68.0	47.6	51.5	46.0	**55.7**
Total System (Average)	**23.8**	**29.0**	**42.3**	**30.6**	**27.2**

Shaded cells are the Areas of Concern tracked throughout this study.

Table 3b: PRES (2017) - User Cost (¢/Mile), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	***160¢***	***143¢***	79¢	***114¢***	**146¢**
Region 2	104¢	84¢	83¢	83¢	**91¢**
Region 3	75¢	85¢	78¢	89¢	**80¢**
Region 4	75¢	79¢	77¢	77¢	**78¢**
Region 5	76¢	80¢	75¢	81¢	**78¢**
Total System (Average)	**119¢**	**102¢**	**81¢**	**97¢**	**107¢**

Shaded cells are the Areas of Concern tracked throughout this study.

Table 3c: PRES (2017) - Total Annual User Costs ($B), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Sum)
Region 1	$8.3	$4.9	$0.1	$1.8	**$15.0**
Region 2	$3.2	$2.7	$1.0	$0.7	**$7.5**
Region 3	$1.6	$1.0	$0.1	$0.6	**$3.3**
Region 4	$0.4	$1.5	$0.1	$0.2	**$2.3**
Region 5	$0.8	$0.6	$0.2	$0.2	**$1.7**
Total System (Summation)	**$14.3**	**$10.6**	**$1.5**	**$3.4**	**$29.9**

Under this scenario, the total twenty-year uninflated investment is $4.4 billion ($222 million per year). AES_{2017} is estimated at 27.2 mph, with a user cost of 107¢ per mile. This represents a 36.9% reduction in speed over the analysis period and a 30.5% increase in user costs per mile.

The projected total annual user costs for the state system in 2017 are $29.9 billion ($1997), which reflects an increase of 88% (4.4% per year) over the analysis period. When the 4.4% annualized increase is normalized, using the average VMT growth rate of 2.2% per year, the results suggest that the cost of each mile of travel is still growing over

2% per year (in constant dollars). When adjusted for inflation (3.3%), the cost is growing about 5.5% per year.

Assuming linear growth for total annual user costs, the calculated twenty-year user costs are $458 billion. The net saving to the users, when compared to the worst case is $130 billion ($6.5 billion annually). According to this scenario, if $4.4 billion ($222 million annually) is invested to preserve the system over the next twenty-year period, highway users could expect to save approximately $130 billion ($6.5 billion annually) in time, safety, and operating costs, as compared with doing nothing to the system. This does not mean that all of Oregon's pavement problems can be solved through an annual investment of $222 million ($1997). Where the cost is $222 million per year and the benefit is $6.5 billion per year, the Benefit-Cost Analysis (BCR) for this scenario would be about 29. This is an excellent rate of return when compared with doing nothing.

Though the Total System Average Speed has dropped from the corresponding existing speed (comparing Table 3a with Table 1a), it is clear that some highways have benefited (or at least held their own) under the Preservation Only scenario. It is assumed that all major pavement problems have been solved, so that any continued reduction in speed over the twenty-year analysis is directly attributed to increased congestion.

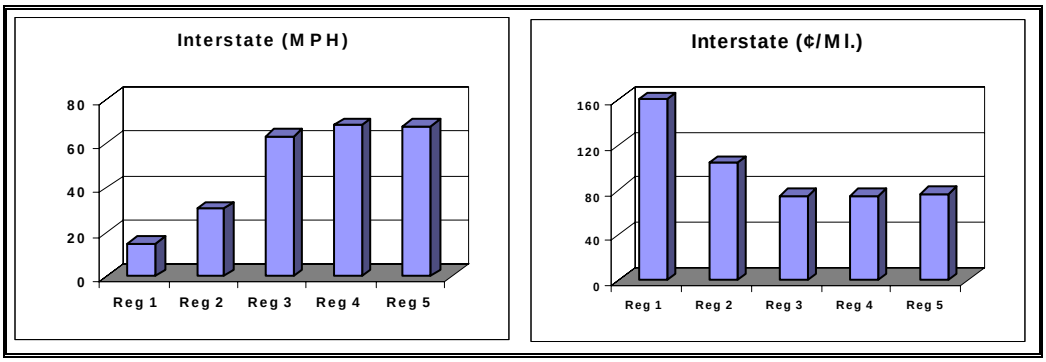
Interstate Classification

The average speed in Region 1 has dropped from 43.9 mph (at the beginning of the analysis) to 15.0 mph (at the end of the analysis), while the user cost has doubled from 81¢ per mile to 160¢ per mile (during the same period). The speed is 37% below the total system average of 23.8 mph, but more clearly about 75% below the speeds in Regions 3, 4 or 5. It is assumed that this is due to the impacts of congestion on the system.

The Interstate speeds and user costs for Regions 3, 4 and 5 are all relatively similar to each other (i.e., ≈ 65 mph and 75¢ per mile – from Table 3a and 3b). Since it is assumed that any speed reduction is directly related to congestion, it should be fair to state that the projected congestion on the Interstate system in Regions 3, 4 and 5 is significantly less than what is projected for Regions 1 and 2.

As a secondary concern, the average Interstate speed for Region 2 has declined from 59.5 mph to 30.4 mph (52-56% below the other three regions), with an associated increase of user costs from 73¢ per mile to 104¢ per mile (28% more than the other three regions). This is also due to congestion.

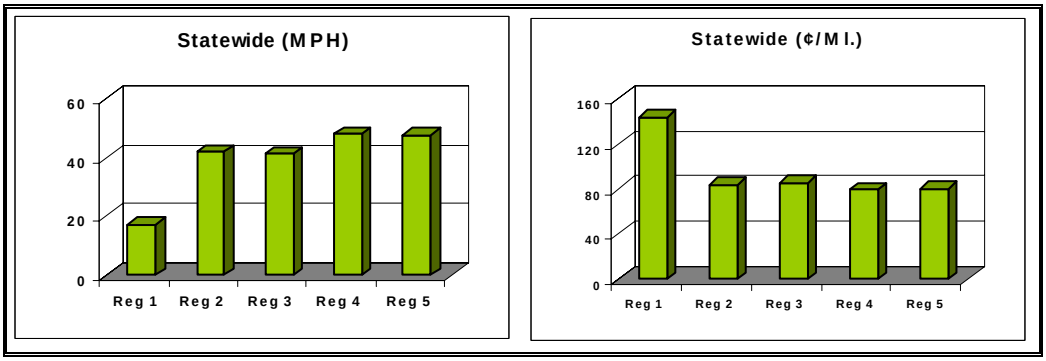
Chart 4a: PRES (2017) - Interstate Speed and User Cost, by Region



Statewide Classification

The user costs in Region 1 increase about 50% over the twenty-year analysis period, while the average speed is halved. The speed is 41% below the total system average of 29.0 mph, and about 60-65% lower than any other region. This seems to be due to increased congestion. Again, the speeds and user costs for the other four regions are similar to each other, but not to Region 1's.

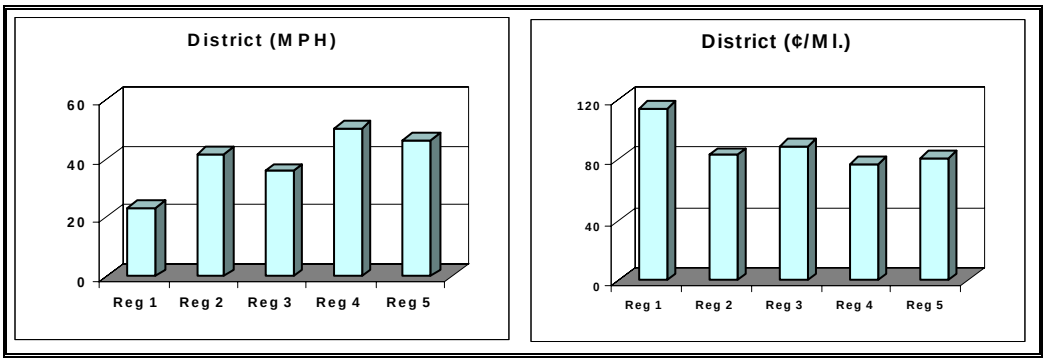
Chart 4b: PRES (2017) - Statewide Speed and User Cost, by Region



District Classification

For this scenario, there appears to be no significant change in the average speed or user cost for Region 1, as compared with the existing 1997 condition.

Chart 4c: PRES (2017) - District Speed and User Cost, by Region



For the most part, a comparison of AES_{1997} (Table 1a) and AES_{2017} (Table 3a) reveals that most of the forecasted **PRES** speeds for 2017 are within ±10% of their corresponding 1997 speeds. The noted exceptions are the Interstate highways in Region 1, and the Interstate and Statewide highways in Regions 1 and 2, primarily identified as the greater urbanized Metro/Willamette Valley area. Both the Interstate and Statewide routes are often major freight routes, where decreased speeds could have a significant effect on Oregon's economy.

The twenty-year funding split between regions for this scenario, based on how HERS allocated the improvements, is presented in Table 4. Three-quarters of the funding is just about equally split between Regions 2, 3 and 4, which also have the lowest current percentage of acceptable pavement (based on pavement condition rating). The split of the VMT_{1997}, VMT_{2017}, and $VMT_{Growth\ Rate}$, by regions, is also provided for comparison purposes.

Table 4a: PRES - HERS Twenty-Year Funding and VMT, by Region

	Total Funding & VMT* Split by Region					State
	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Total**
PRES (TOTAL)	$628M (14%)	$1,189M (27%)	$646M (15%)	$994M (22%)	$988M (22%)	**$4,445M (100%)**
FoB_{1997}**	83%	71%	82%	73%	81%	**77%**
FoB_{2017}***	79%	87%	86%	92%	95%	**89%**
VMT_{1997}	6,871 (36%)	5,832 (30%)	2,930 (15%)	2,032 (11%)	1,626 (8%)	**19,291 (100%)**
VMT_{2017}	10,289 (37%)	8,290 (29%)	4,129 (15%)	2,889 (10%)	2,229 (8%)	**27,826 (100%)**
$VMT_{Growth\ Rate}$	*1.025*	*1.021*	*1.020*	*1.021*	*1.019*	***1.022***

*VMT in Millions
**From Pavement Unit
***From HERS Analysis

Chart 5: PRES - HERS Twenty-Year Pavement Condition (FoB), by Region

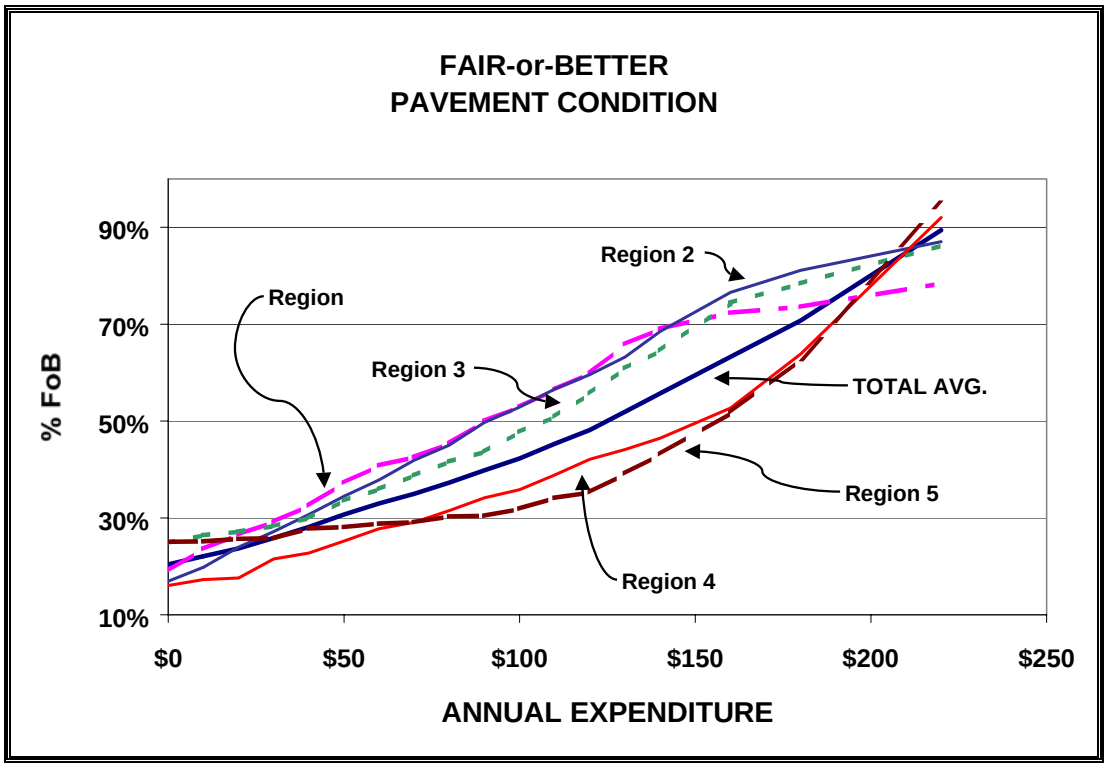


Table 5 shows how the pavement condition (FoB) improves with increased annual investments.

Under **PRES** scenario, the model is allowed to make all required pavement improvements, when deemed necessary. No attempt is made to maintain or achieve any specific pavement condition goals. A breakdown of the total number of miles improved is presented in Table 5. The model identifies an additional 842 miles that required shoulder improvements, which are categorized as **Safety** work in OHP (i.e., $PRES_{Safety}$ = *SAFETY* work). Though the safety work was not included in the analysis, the pavement condition was improved.

Table 5: PRES - Total Number of Miles Improved, by Region

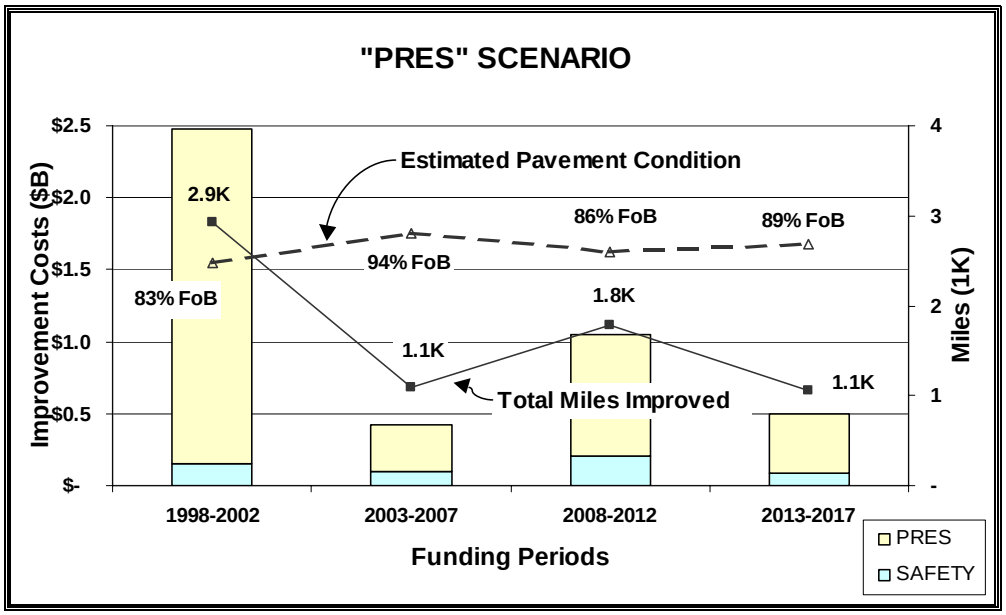
	Total Number of Miles Improved Split by Region					State
	Region 1	Region 2	Region 3	Region 4	Region 5	Total
$PRES_{ONLY}$*	792	1,600	818	1,307	1,496	**6,014** **(300.7 ml./yr.)**
$PRES_{Safety}$*	*65*	*159*	*139*	*276*	*203*	***842*** **(42.1 ml./yr.)**
PRES (TOTAL)	**857**	**1,759**	**958**	**1,583**	**1,699**	**6,856** **(342.8 ml./yr.)**

*$PRES_{Safety}$ are sections identified by HERS for minor *safety* type improvement, **only pavement improvements allowed**.

According to this scenario, about 343 miles per year would need to be improved. Of that, approximately 42 miles per year would require safety work.

The total state system needs, split by the four funding periods are shown in Chart 6, where 71% of the total twenty-year system needs is simulated during the first 5-year funding period. During the same period, the pavement condition is improved from the current 77% FoB to 82% FoB. To some degree, this large percentage of simulated needs during the first funding period reflects the unmet (backlog) improvement needs that currently exist on the state system. The actual extent of the unmet needs is beyond the scope of this analysis.

Chart 6: Total PRES Improvement Costs, by Funding Period



Once a target pavement condition is achieved, considerably less funding is required to maintain this level.

Preservation and Modernization (MOD-RR)

The **MOD-RR** scenario is essentially the same HERS analysis used for the "Feasible Needs" scenario in the OHP, with noted exceptions. The goal of this analysis is to simulate modernization improvements in accordance with 1) solutions identified by corridor plans or local transportation system plans, 2) specific projects identified by the various regional needs lists, or 3) improvements identified by the Highway Performance Monitoring System Analytical Process that may or may not have been revised by regional personnel. Where modernization improvements are not specifically identified,

preservation improvements specified by the Pavement Management System (PMS) are simulated to increase the overall system pavement condition to a 90% FoB threshold by 2010. In all cases, the model user controlled the model's selection of improvements, both by type and year.

Table 6a: MOD-RR (2017) - AES_{1997} (MPH), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	***14.9***	***17.6***	46.1	***25.4***	**17.0**
Region 2	***50.2***	44.1	40.7	42.2	**45.4**
Region 3	63.4	42.3	45.6	35.8	**49.1**
Region 4	68.7	48.7	45.4	51.1	**51.8**
Region 5	68.3	48.1	51.2	44.9	**56.0**
Total System (Average)	**25.7**	**29.7**	**43.8**	**32.7**	**28.7**

Shaded cells are the Areas of Concern tracked throughout this study.

Table 6b: MOD-RR (2017) - User Cost (¢/Mile), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	***160¢***	***134¢***	76¢	***105¢***	**144¢**
Region 2	76	80¢	81¢	80¢	**78¢**
Region 3	75¢	82¢	77¢	87¢	**79¢**
Region 4	75¢	77¢	79¢	76¢	**77¢**
Region 5	75¢	78¢	76¢	80¢	**76¢**
Total System (Average)	**112¢**	**99¢**	**79¢**	**92¢**	**102¢**

Shaded cells are the Areas of Concern tracked throughout this study.

Table 6c: MOD-RR (2017) - Total Annual User Costs ($B), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Sum)
Region 1	$8.3	$4.7	$0.1	$1.6	**$14.8**
Region 2	$2.3	$2.6	$0.9	$0.7	**$6.5**
Region 3	$1.6	$1.0	$0.1	$0.6	**$3.3**
Region 4	$0.4	$1.5	$0.1	$0.2	**$2.2**
Region 5	$0.8	$0.5	$0.2	$0.2	**$1.7**
Total System (Summation)	**$13.4**	**$10.4**	**$1.5**	**$3.3**	**$28.5**

Under the **MOD-RR** scenario, the total twenty-year uninflated investment is $7.8 billion ($392 million per year). AES_{2017} is estimated at 28.7 mph, with a user cost of 102¢ per mile. This reflects a 33.4% reduction in speed and a 24.4% increase in user costs per mile over the analysis period.

The projected total annual user costs in 2017 are $28.5 billion ($1997), which reflects an increase of 79.3% (4.0% per year) over the analysis period. When the 4.0% annualized

increase is normalized, using the average VMT growth rate of 2.2% per year, the results suggest that the cost of each mile of travel is still growing over 1.5% per year (in constant dollars). When adjusted for inflation (3.3%), the cost is growing about 5.0% per year.

Assuming a linear growth for the total annual user costs, the estimated total twenty-year user costs are $444 billion. The net saving to the users, when compared to the worst case is $144 billion, and when compared to the **PRES** scenario, is $14 billion. According to this scenario, if an additional $3.8 billion ($191 million annually) is invested to modernize or upgrade the system**,** beyond preservation, highway users would save approximately $14 billion ($700 million annually) in time, safety, and operating costs as compared with preservation only. This does not mean that most of Oregon's modernization problems can be solved through an annual investment of $191 million ($1997). However, where the cost is $191 million per year and the benefit is $700 million per year, the BCR for this scenario would be about 3.7, which is a reasonable rate of return.

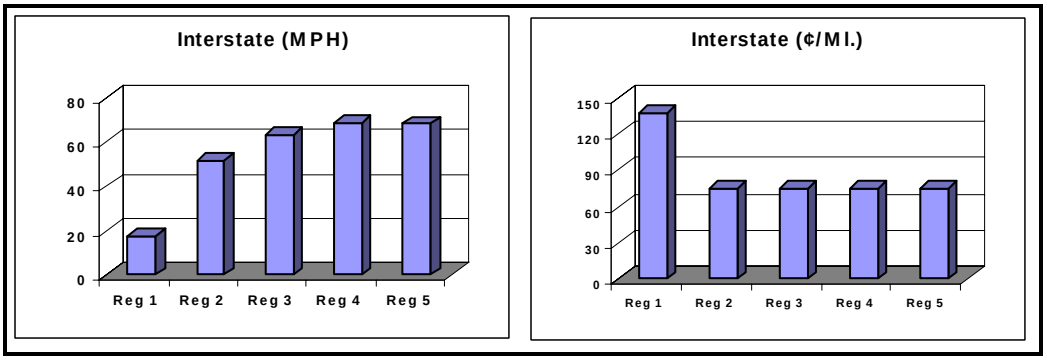
For this scenario, most pavement problems are solved, and many of the other conditions (i.e., congestion/geometric/safety) are enhanced. The average speed and user costs per mile are clearly improved with the implementation of the modernization element. However, not enough is done for the Interstate and Statewide highways in Region 1.

Interstate Classification

Though the user costs in Region 1 have decreased by 14% from the **PRES** scenario, the average speed has only slightly improved. The speed is 39% below the total system average of 29.4 mph, and remains about 70% below the average speeds in Regions 3, 4 or 5. Again, this is due to the impacts of congestion on the system. The user costs are about 45% higher per mile when compared with any other region.

A secondary concern identified by the speed on Region 2's Interstate highways (51.5 mph), shows significant improvement when compared with the **PRES** scenario (30.4 mph); however, the speed is still 19-25% below that of the other three regions, indicating an influence from congestion.

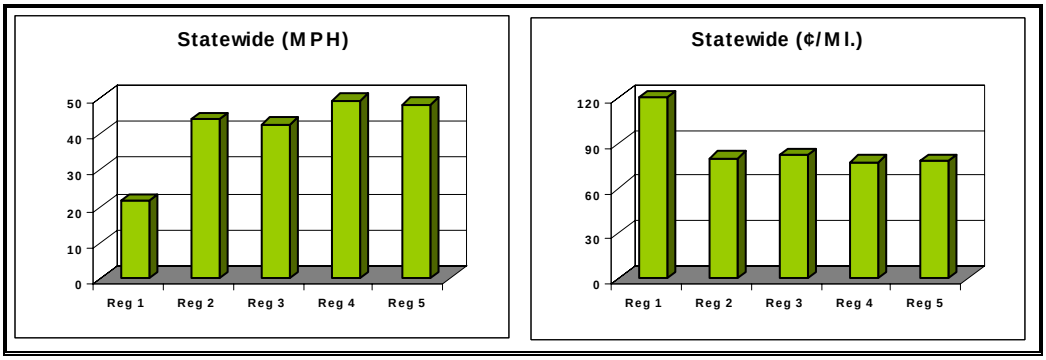
Chart 7a: MOD-RR (2017) - Interstate Speed and User Cost, by Region



Statewide Classification

Region 1's Statewide highway system seems to suffer the same fate as the Interstate highway system. The speed is 36% below the total system average of 33.3 mph and about 50-55% lower than any other region. At the same time, the user costs are about 30% higher than any other region.

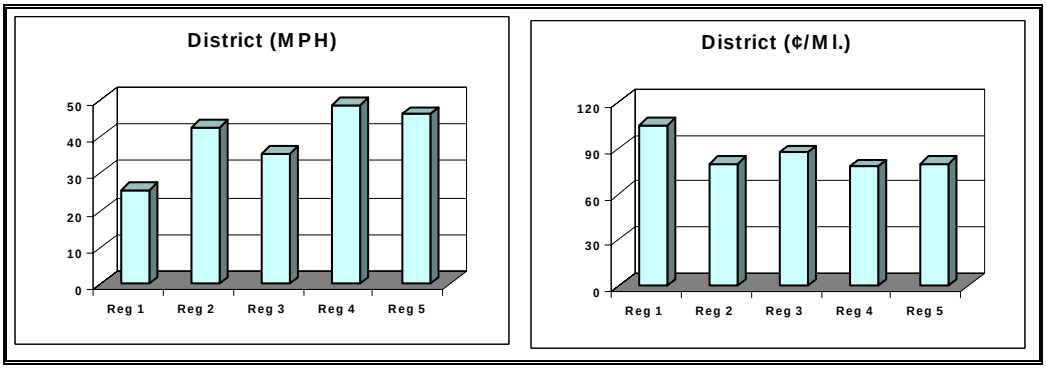
Chart 7b: MOD-RR (2017) - Statewide Speed and User Cost, by Region



District Classification

Changes in the Regional and District highways between the scenarios are minimal.

Chart 7c: MOD-RR (2017) - District Speed and User Cost, by Region



The twenty-year funding split between the five regions, based on how HERS allocated the improvements, is presented in Table 7. The funding is further split between modernization (36% of total system needs), preservation (41% of total system needs), and preservation-safety (23% of total system needs), i.e., shoulder widening and minor alignment improvements.

Table 7: MOD-RR - Twenty-Year Funding, by Region

	Total Funding Split by Region					State
	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Total**
MOD-RR (Total)	**$1,178M (15%)**	**$2,166M (28%)**	**$1,248M (16%)**	**$1,711M (22%)**	**$1,534M (20%)**	**$7,837M (100%)**
- $MOD_{Reg.}$	$372M	$803M	$308M	$311M	$85M	**$1,880M**
- $PRES_{ONLY}$	$621M	$878M	$595M	$867M	$1051M	**$4,013M**
- $PRES_{Safety}$	$184M	$485M	$345M	$532M	$398M	**$1,944M**
FoB_{1997}*	83%	71%	82%	73%	81%	**77%**
FoB_{2017}**	85%	89%	90%	87%	95%	**90%**

*From Pavement Unit
**From HERS Analysis

For this scenario, 55% of the modernization needs are in Region 1 and 2 ($811 million and $917 million, respective) where the majority of the congestion problems exist.

As compared with the 1997 condition, AES_{2017} declines substantially in both Regions 1 and 2 (specifically for Interstate and Statewide highways) even though there are considerable modernization improvements made under this scenario. Clearly, not enough is being done to solve the congestion problems.

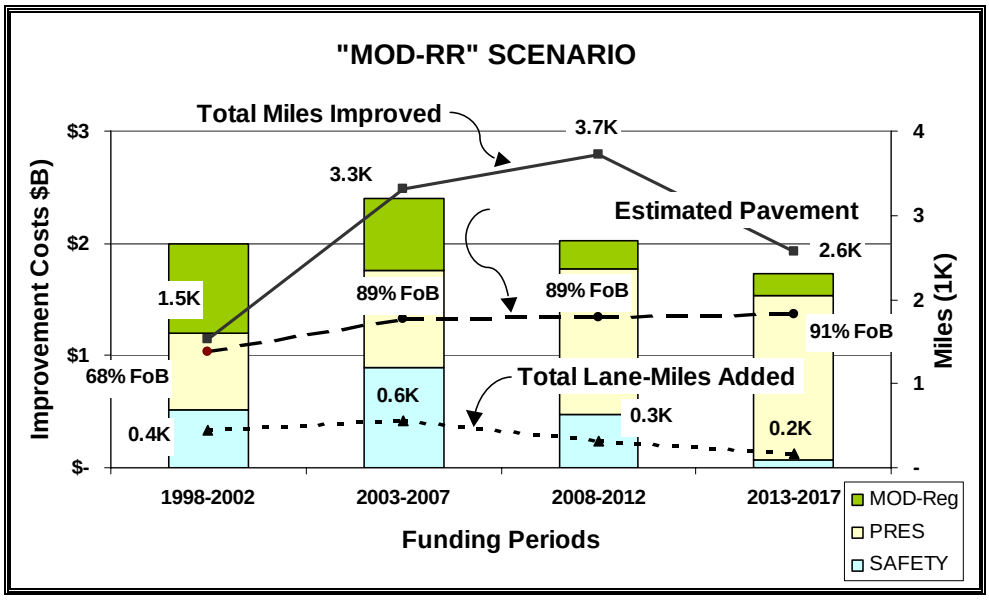
Table 8: MOD-RR - Total Number of Miles Improved, by Region

	Total Number of Miles Improved Split by Region					State
	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Total**
$MOD_{Reg.}$	332	517	249	312	225	**1,635 (81.8 ml./yr.)**
$PRES_{ONLY}$*	707	1,470	873	1,590	2,059	**6,699 (335.0 ml./yr.)**
$PRES_{Safety}$*	223	638	429	833	666	**2,789 (139.5ml. /yr.)**
MOD-RR (Total)	**1,262**	**2,625**	**1,550**	**2,736**	**2,951**	**11,124**

*$PRES_{Safety}$ Sections identified by HERS for minor *safety* type improvement, **improvements were made**.

According to this analysis, about 82 miles per year (≈15%) would need to be modernized, and about 475 miles per year would need to be preserved, with 140 miles (≈25%) of these requiring safety improvements.

Chart 8: Total MOD-RR Improvement Costs, by Funding Period



Preservation and Modernization (MOD-HC)

From the standpoint of mobility by auto, the **MOD-HC** scenario addresses all the congestion needs. The goal of this analysis is to simulate improvements for all needs identified by the HERS, including all pavement, geometric and congestion problems. All characteristics of a particular highway section below the MTCs in any respect are considered deficient. Multiple lane improvements are allowed; however, all additional lanes, after an initial single lane in each direction, are simulated at a considerably higher cost (**HC**).

Table 9a: MOD-HC (2017) - AES_{1997} (MPH), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	***61.2***	***40.5***	45.9	***26.4***	**44.6**
Region 2	66.1	46.0	41.6	43.3	**50.6**
Region 3	65.6	44.6	48.3	36.6	**51.2**
Region 4	68.8	50.8	49.2	52.7	**53.7**
Region 5	68.3	48.1	52.0	46.6	**56.1**
Total System (Average)	**64.1**	**44.8**	**44.1**	**33.3**	**48.9**

Shaded cells are the Areas of Concern tracked throughout this study.

Table 9b: MOD-HC (2017) - User Cost (¢/Mile), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Avg.)
Region 1	***60¢***	***78¢***	76¢	***102¢***	**73¢**
Region 2	63¢	78¢	80¢	80¢	**73¢**
Region 3	72¢	81¢	76¢	86¢	**77¢**
Region 4	75¢	76¢	77¢	75¢	**76¢**
Region 5	76¢	79¢	75¢	80¢	**77¢**
Total System (Average)	**65¢**	**78¢**	**78¢**	**91¢**	**74¢**

Shaded cells are the Areas of Concern tracked throughout this study.

Table 9c: MOD-HC (2017) - Total Annual User Costs ($B), by Region and roadway classification (SCS)

	Interstate	Statewide	Regional	District	Total (Sum)
Region 1	$3.1	$2.6	$0.1	$1.6	**$7.5**
Region 2	$1.9	$2.5	$0.9	$0.7	**$6.0**
Region 3	$1.5	$0.9	$0.1	$0.6	**$3.2**
Region 4	$0.4	$1.5	$0.1	$0.2	**$2.2**
Region 5	$0.8	$0.6	$0.2	$0.2	**$1.7**
Total System (Summation)	**$7.7**	**$8.1**	**$1.5**	**$3.2**	**$20.6**

This scenario is the only case that demonstrates improved highway performance for speed and user costs per mile. The twenty-year total uninflated investment is $18.2 billion ($910 million per year). The average speed increases to 48.9 mph with a user cost of 74¢. This reflects a 13.5% benefit to the system, and a 9.8% reduction in user costs per mile over the analysis period.

The projected total annual user costs in 2017 are $20.6 billion ($1997), which reflects an increase of 29.6% (1.5% per year) over the analysis period. When the 1.5% annualized increase is normalized, using the average VMT growth rate of 2.2% per year, the results suggest that the cost of each mile of travel is declining by about 0.7% per year (in constant dollars). When adjusted for inflation (3.3%), the cost is growing about 2.5% per year.

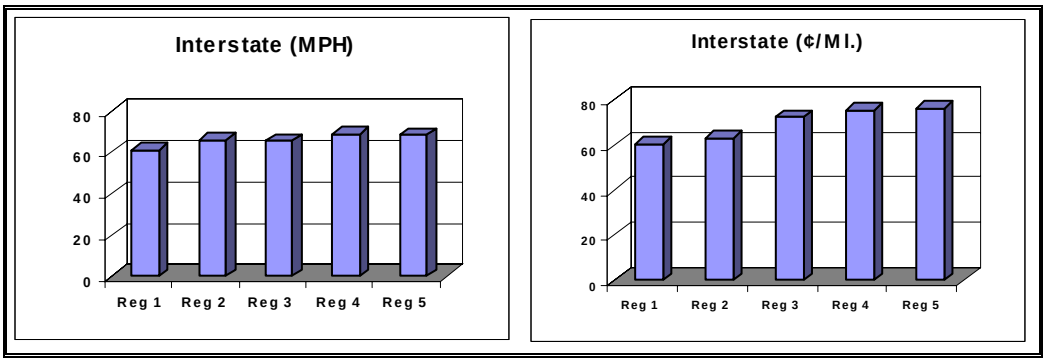
Assuming linear growth for the total annual user costs, the calculated twenty-year cost is $365 billion. The net saving to the users when compared to the worst case is $223 billion, and when compared to the **PRES** scenario is $93 billion. According to this scenario, if an additional $15.5 billion ($775 million annually) is invested to modernize or upgrade the system, above and beyond preservation, highway users would save approximately $93 billion ($4.7 billion annually) in time, safety, and operating costs, as compared with preservation only. This does not mean that all of Oregon's modernization problems can be solved through an annual investment of $775 million ($1997). However, where the cost is $775 million per year and the benefit is $4.7 billion per year, the BCR for this scenario would be about 6, which is a reasonable rate of return.

Interstate Classification

In this scenario, all system deficiencies are economically resolved (meaning there may have been other solutions, but these made the best economical sense). The average speed and user cost per mile for Region 1's Interstate highways demonstrate significant improvement, as compared with all other scenarios. The average speed of 61.2 mph is about 5% below the total system average of 64.1 mph, and between 7 and 11% below all other regions. The cause for these speed reductions is assumed to be something other than congestion/pavement needs. For the first time, the average user cost per mile (60¢ per mile) is better than the total system average (65¢ per mile).

There no longer appears to be a congestion problem on Region 2's Interstate highways.

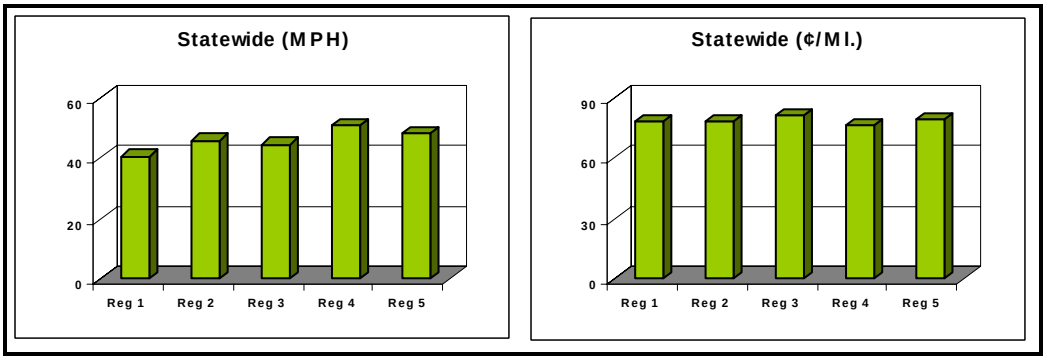
Chart 9a: MOD-HC (2017) - Interstate Speed and User Cost, by Region



Statewide Classification

Region 1's Statewide highways show dramatic improvement under this scenario. The average speed of 40.5 mph is about 10% below the total system average of 44.8 mph, and the average user cost equals the total system average at 78¢ per mile. The cause for these speed reductions is assumed to be something other than congestion/pavement needs.

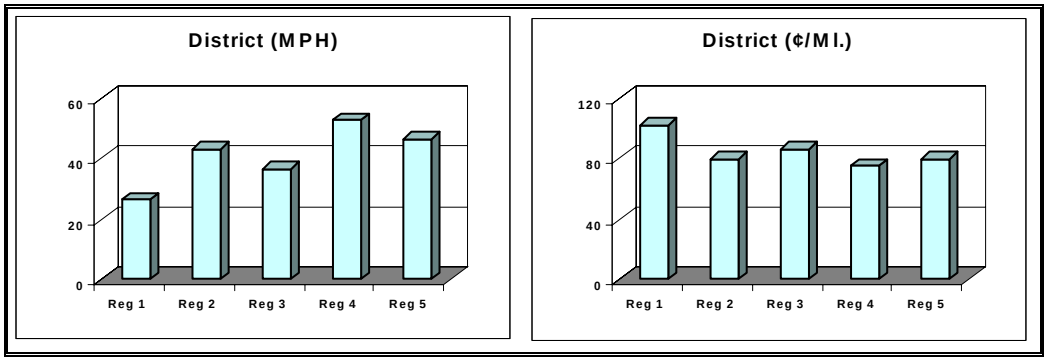
Chart 9b: MOD-HC (2017) - Statewide Speed and User Cost, by Region



District Classification

Once again, the change in Region 1's average District highway speed (26.4 mph) is minimal, at about 21% below total system average (33.3 mph). This suggests that the problems are not congestion related.

Chart 9b: MOD-HC (2017) - District Speed and User Cost, by Region



The funding split by region, based on how HERS allocated the improvements, is shown in Table 10. About three-quarters of the total $18.2 billion improvements are in Regions 1 and 2, at 51% ($9.2 billion) and 24 % ($4.5 billion), respectively. The majority of these improvements are directly attributed to the congestion on the system, both current and future. Using Region 1 as an example, the total price tag for all improvements is $9.2 billion, of which $8.4 billion are modernization improvements. The difference between adding a single lane here or there (**Reg**.) compared to adding multiple lanes (**HC**) is staggering, indicating the significant degree of congestion modeled by the software; 95.3% of the region's modernization improvements are in response to congestion.

Table 10: MOD-HC - Twenty-Year Funding, by Region

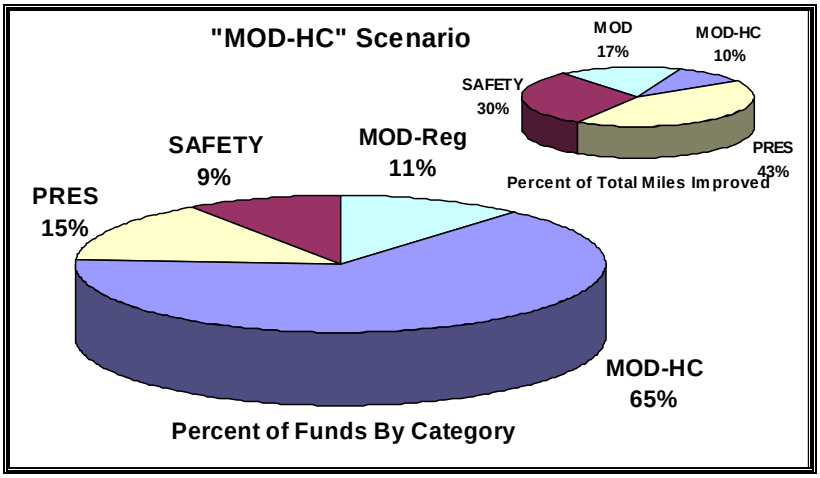
	Total Cost Split by Region					State
	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Total**
MOD-HC (Total)	**$9,235M (51%)**	**$4,456M (24%)**	**$1,795M (10%)**	**$1,474M (8%)**	**$1,261M (7%)**	**$18,221M (100%)**
- MOD_{ALL}	*$8,412M*	*$3,332M*	*$1,148M*	*$579M*	*$329M*	***$13,800M***
HC	***$8,013M***	***$2,407M***	***$835M***	***$340M***	***$112M***	***$11,707M***
Reg.	***$399M***	***$925M***	***$313M***	***$239M***	***$217M***	***$2,093M***
- $PRES_{ONLY}$	*$689M*	*$737M*	*$329M*	*$522M*	*$426M*	***$2,703M***
- $PRES_{Safety}$	*$134M*	*$388M*	*$317M*	*$372M*	*$507M*	***$1,718M***
FoB_{1997}*	83%	71%	82%	73%	81%	**77%**
FoB_{2017}**	88%	88%	90%	89%	94%	**90%**

*From Pavement Unit
**From HERS Analysis

As demonstrated in Chart 10, a large percent of the overall system needs is associated with high cost improvements. The majority of these improvements are in the Willamette

Valley/Metro area. About one-quarter of the simulated expenditures are categorized as preservation or safety improvements, resulting in about three-quarters of the total miles improved.

Chart 10: Total State Funding Percent Split, by Improvement Category



Again, no attempt is made to maintain current pavement conditions or achieve improved FoB goals. The model is allowed to make all required improvements.

While the total improvement costs, per region, per improvement type, are listed in Table 10, the associated number of miles improved are listed in Table 11. Of the 565 miles improved for Region 1, 65% (366 miles) is for added lanes, identified as high cost improvements.
The HERS model made improvements on 2,328 miles of roadway in Region 2 at a total improvement cost of $4.5 billion, which included the addition of 865 lane-miles to the system. About half the improvement costs for this region are for high cost lanes to address congestion problems.

Though the AES analysis failed to show any effects of congestion on speed for Regions 3, 4 and 5, the assumption that localized congestion exists in those regions is clearly indicated in Tables 10 and 11. For the twenty-year period, there are about $835 million of HC congestion improvements in Region 3, covering 113 miles of roadway and adding 258 lane-miles. Similar analysis can be shown for Regions 4 and 5. All high cost miles are identified in Map 2.

Table 11: MOD-HC - Total Number of Miles Improved, by Region

	Total Number of Miles Improved Split by Region					State Total
	Region 1	Region 2	Region 3	Region 4	Region 5	
MOD_{All}	565	912	283	249	261	**2,270** (113.5 ml./yr.)
- HC	***366***	***315***	***113***	***37***	***17***	***848***
- Reg.	***199***	***597***	***170***	***212***	***244***	***1422***
$PRES_{ONLY}$*	552	886	474	839	738	**3,489** (174.4 ml./yr.)
$PRES_{Safety}$*	173	531	414	605	784	**2,507** (125.3 ml./yr.)
MOD-HC (Total)	**1,290**	**2,328**	**1,171**	**1,693**	**1,784**	**8,265**
Total Added Lane-Miles	***1,299***	***865***	***258***	***147***	***23***	***2,591***

*$PRES_{Safety}$ Sections identified by HERS for minor safety type improvement, **improvements were made**.

According to this analysis, about 114 (≈27%) miles per year would need to be modernized, and about 300 miles per year would need to be preserved, including 125 (≈30%) miles per year of safety improvements.

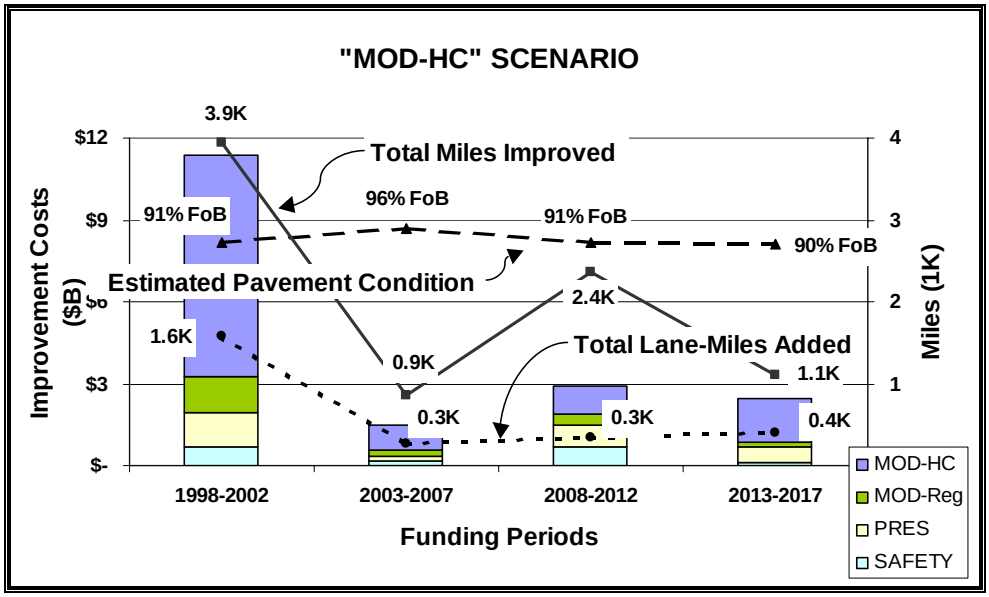
The preservation improvements decrease by about 37% (yearly) from the **MOD-RR** scenario. This is due to the increased number of miles that are modernized. In general, the greater the emphasis on modernization, the less preservation work is required since adding lanes reduces the rate of pavement wear. However, the difference in cost between the two improvements does not make it an equal trade-off.

Summary of MOD-HC

The **MOD-HC** scenario is summarized in Chart 11. The most notable observation is the extremely large investment ($11.4 billion) that is simulated during the first funding period (1998-2002), which comprises 62% of the total twenty-year expenditure (62% of $18.2 billion). The subsequent needs are identified accordingly (i.e., pavement condition, overall speed, user costs, etc). The outlay for just the high cost lanes, or congestion fix, accounts for almost three-fourths of the funding period's $11.4 billion price tag.

In addition, almost half (≈47%) the total number of miles improved are also simulated during the same single funding period, resulting in an enhancement of average pavement condition (from 77% FoB_{1998} to 91% FoB_{2002}).The improved pavement condition is maintained with moderate expenditure during subsequent funding periods.

Chart 11: Total MOD-HC Improvement Costs, by Funding Period



It should be clearly realized that all numbers would change (perhaps significantly) depending on which types of improvements are acceptable and the order in which they are implemented. Additional analysis would be required to answer specific "what if" questions.

DISCUSSION

Vehicle Miles Traveled (VMT)

The existing and future VMT percentages, by region and highway classification (SCS), have been provided in Tables 12a and 12b, respectively. In the total state system, about two-thirds of the total existing VMT (1997) is located primarily in the Willamette Valley area, in Regions 1 and 2 (35.6 % and 30.2%, respectively). Just over half of the total existing VMT is on the Interstate and Statewide system in Regions 1 and 2.

The majority of the existing VMT on the Interstate and District systems can be found in Region 1 (42.3% and 43.6% respectively). While 62.6% of the total traffic on the Regional system can be found in Region 2.

Table 12a: Existing VMT for State Highway System, by Region, by SCS (from HERS)

VMT_{1997} (MILLIONS)					
	Interstate	**Statewide**	**Regional**	**District**	**Total**
Region 1	3,366 (42.3%)	2,220 (30.5%)	118 (8.6%)	1,164 (43.6%)	**6,871 (35.6%)**
Region 2	2,050 (25.7%)	2,323 (31.9%)	856 (62.6%)	602 (22.6%)	**5,832 (30.2%)**
Region 3	1,418 (17.8%)	859 (11.8%)	127 (9.2%)	523 (19.6%)	**2,930 (15.2%)**
Region 4	431 (5.4%)	1,324 (18.2%)	102 (7.4%)	173 (6.5%)	**2,032 (10.5%)**
Region 5	698 (8.8%)	551 (7.6%)	171 (12.4%)	205 (7.7%)	**1,626 (8.4%)**
Total System	**7,966 (100%) (41.3%)***	**7,279 (100%) (37.7%)***	**1,377 (100%) (7.1%)***	**2,669 (100%) (13.8%)***	**19,292 (100%) (100%)***

NOTE: VMT is not a measure of congestion. The model is based on trends and is not responsive to shifts in modes, routes or locations.

For each classification, the difference by region between VMT_{1997} (existing) and VMT_{2017} (projected) appears to be relatively minor, i.e., all values are within a several percentage points of each other.

Table 12b: Projected VMT for State Highway System, by Region, by SCS (from HERS)

VMT_{2017} (MILLIONS)					
	Interstate	**Statewide**	**Regional**	**District**	**Total**
Region 1	5,176 (43.2%)	3,387 (32.5%)	170 (9.1%)	1,555 (43.9%)	**10,289 (37.0%)**
Region 2	3,064 (25.6%)	3,254 (31.2%)	1,148 (61.3%)	822 (23.2%)	**8,290 (29.8%)**
Region 3	2,082 (17.4%)	1,168 (11.2%)	191 (10.2%)	686 (19.4%)	**4,129 (14.8%)**
Region 4	593 (5.0%)	1,922 (18.4%)	138 (7.4%)	235 (6.6%)	**2,889 (10.4%)**
Region 5	1,055 (8.8%)	702 (6.7%)	225 (12.0%)	245 (6.9%)	**2,229 (8.0%)**
Total System	**11,971 (43.0%)**	**10,435 (37.5%)**	**1,874 (6.7%)**	**3,544 (12.7%)**	**27,827 (100%)**

Table 13 shows how the yearly growth rate varies by region and classification. The average state growth rate is about 2.2% per year.

Table 13: Projected VMT for State Highway System, by Region, by SCS (from HERS)

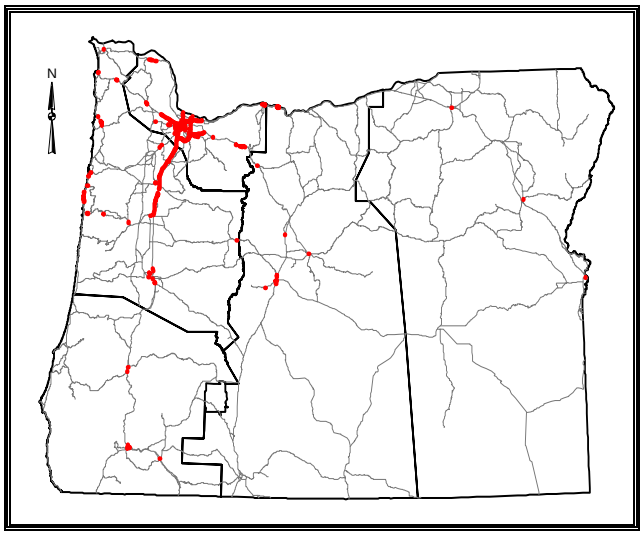
$VMT_{20\text{-Year Growth Rate}}$					
	Interstate	**Statewide**	**Regional**	**District**	**Total (Avg.)**
Region 1	1.027	1.026	1.022	1.017	**1.025**
Region 2	1.025	1.020	1.017	1.018	**1.021**
Region 3	1.023	1.018	1.025	1.016	**1.020**
Region 4	1.019	1.023	1.018	1.018	**1.021**
Region 5	1.026	1.014	1.016	1.010	**1.019**
Total System (Average)	**1.025**	**1.022**	**1.018**	**1.016**	**1.022**

Congestion

The **MOD-HC** scenario dispersed about two-thirds of the scenario's total expenditure during the first funding period ($11.4 billion; see Table 15), of which $8 billion (Table 10) went specifically to build additional high cost lanes, indicating some kind of related problems. This does not imply that all these needs are existing (or backlog) to the system. However, the model suggests that a significant congestion problem will exist within a very short period of time (assuming that the problem does not already exist). Additional analysis could identify the actual backlog.

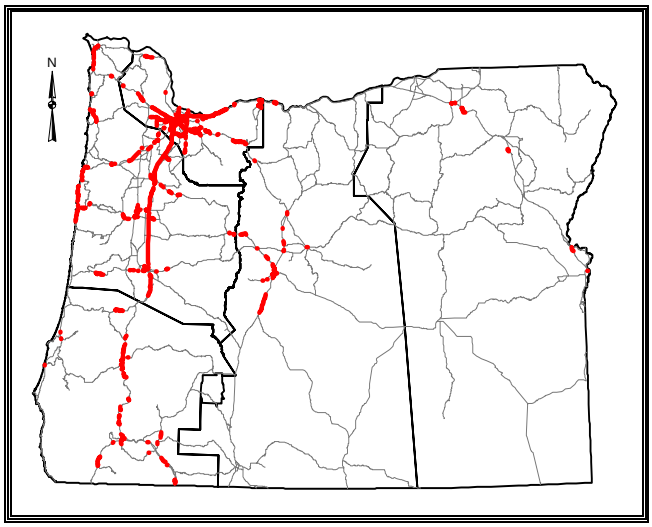
As previously mentioned, the majority of the congestion problems are in the Metro/Willamette Valley area where most of the traffic is found. Again, most of the congestion is located on the Interstate and Statewide routes, which generally serve as freight routes. The high cost improvements for the first funding period (1998 - 2002) are shown in Map 1, below.

Map 1: Location of High Cost Improvements (1998-2002)



This study does not suggest that there are no congestion problems in Regions 3, 4 or 5. Local congestion undoubtedly exists, but pockets of local congestion, particularly on the state system, are not readily apparent at the regional level. However, this local congestion may have a direct effect on the local economy. A much more detailed analysis is required to determine where and how much congestion potentially exists.

Map 2: Location of All High Cost Improvements (1998-2017)



Summary

The effects of modernization and preservation improvements, at various funding levels, are tracked using average effective speed, user cost per mile, and total annual user costs. The data from the previous sections are summarized in Table 14.

Table 14: Comparison of Speed and User Cost Results by Case Scenarios, in 2017

	STATE SYSTEM AVERAGES				
	Total 20-Year Investment [$B]	**AES [MPH]**	**User Cost Per Mile [¢]**	**Total Annual User Costs [$B]**	**Total 20-Year User Costs [$B]**
Current Condition	n/a	43.1	83	$15.9	n/a
No Improvements	$0.0	17.1	154	$42.9	$588
PRES	$4.4	27.2	107	$29.9	$458
MOD-RR	$7.8	28.7	102	$28.5	$444
MOD-HC	$18.2	48.9	74	$20.6	$365

In generalizing the state averages, it is obvious that under feasible scenarios, future speeds will continue to decline while the corresponding user costs per mile will increase. The only scenario where the speed and user costs actually show gains is in **MOD-HC**, when infeasible improvements are made at a "higher cost."

In the **PRES** scenario, the twenty-year average speeds in Regions 3, 4, and 5 are all relatively close to the existing speeds. Since these regions seem to lack significant congestion problems, it would appear that they have achieved a reasonably steady state condition. Consequently, the best investment for those regions would be in preservation projects with a moderate modernization investment to deal with local congestion.

Table 15: Funding Path Expenditures ($ Percentage of Scenario), Pavement Condition

Funding Path Expenditures ($/Funding Period)					
	1998-2002	**2003-2007**	**2008-2012**	**2013-2017**	**Total**
PRES	$2,474M (56%) 82%FOB	$424M (10%) 93%FOB	$1,048M (24%) 86%FOB	$499M (11%) 89%FOB	**$4,445** **(100%)**
MOD-RR	$1,994M (25%) 68%FOB	$2,404M (31%) 88%FOB	$2,011M (26%) 88%FOB	$1,428M (18%) 90%FOB	**$7,836M** **(100%)**
MOD-HC	$11,377M (62%) 91%FOB	$1,464M (8%) 96%FOB	$2,910M (16%) 91%FOB	$2,470M (14%) 90%FOB	**$18,221M** **(100%)**

ODOT's FoB pavement condition rating, as defined in OHP, was only a target for the **MOD-RR** scenario. For the other two scenarios, the HERS model simulated all improvements based solely on the deficiency levels, or needs, as defined by the minimum

tolerable conditions (MTC). A direct correlation between MTC's and FoB was not established for this study; as a result, greater pavement deficiencies were tolerated before improvements were triggered.

The numbers reported here do not reflect modernization or safety needs that could not be modeled, i.e., intersections, interchanges, signals, nor do they include investment needs from the other OHP categories (i.e., bridge, maintenance, operations, etc). The needs do not include costs for preliminary engineering (PE), construction engineering (CE), or right-of-way acquisition (R/W).

CONCLUSION

The results show that "preservation only" scenario generally appears to be an adequate approach in the less populated (or less traveled) areas, predominantly Regions 3, 4, and 5. It also seems to be a successful way to manage some of the secondary highway sections in Regions 1 and 2. However, this scenario is unbearable for the major transportation/commuter routes which are located in the greater Willamette Valley area, which are either already congested or are expected to be in the future at the current rate of growth. These routes are primarily, but not exclusively, located in Regions 1 and 2 (i.e., Interstate and Statewide). In order to avoid total gridlock in the future, some degree of modernization will need to be addressed and implemented.

Some of the congestion problems are reduced with the addition of minor modernization improvements, as outlined in the preservation and region-restricted modernization scenario (the 1999 Oregon Highway Plan's Feasible Needs Scenario). However, Oregon's average speed still declines 26% over the same analysis period, while the average user costs increase 17%.

The third scenario evaluates the unconstrained funding scenario in which all congestion problems are addressed. Though the average speed actually increases 14% and the average user costs decrease 10%, the price tag for all the improvements increases to an unrealistic level, over four times that of simply "protecting the current infrastructure."

The HERS model implements only those improvements that are economically justified. ODOT may fund highway improvements that would not pass the same economic test, but may have other equally valuable considerations.

The Oregon Transportation Commission will be making tough investment decisions. Their decisions will determine which areas should be modernized and what types of improvements should be made. Though the HERS analysis helps present a clear picture of the condition of the highway system under different funding scenarios and time frames, it is only one piece of the total transportation puzzle. Additional needs, as defined in OHP (i.e., bridge, maintenance, safety, and operations), fall outside the

modeling parameters and cannot be adequately simulated. Additional analysis is required to fine tune the process in order to determine the total highway system needs (i.e., intersection/interchange improvements, signal timing, and salmon recovery, etc).

The summarized results of this study indicate that:

- The highest rate of return is with the preservation investments at about $50 million a year.
- Between $50 million and $100 million per year, preservation improvements are still the best investment, but the rate of return begins to decline,
- After $100 million per year, some modernization improvements should be thrown into the mixture. Congestion issues begin to have more prominence and need to be addressed.
- After $160 million per year, preservation appears to cease contributing to the performance on the system. Only congestion driven improvements will show any significant improvement for system performance beyond this investment level.

CAVEATS

This analysis does not:

- Reflect the pavement goals adopted by the Region Roundtable Team.
- Reflect the revised volume-to-capacity standards adopted by OHP. (NOTE: The 1999 Oregon Highway Plan was not yet adopted at the time of this study. However, though the numbers might change slightly with the new standards, they would all be relative to each other, and the conclusions would still be the same)
- Reflect ODOT's pavement deterioration rate, used by the Pavement Management System. (NOTE: The HERS pavement deterioration rate was not calibrated to ODOT's deterioration rate. An accelerated deterioration would result in greater needs and earlier resurfacing improvements (more improvements-sooner). A decreased rate would have the opposite effect. Either way, all scenarios are relative.)
- Reflect actual construction costs used by the Pavement Management System. The values here are based on 1997 dollars developed for the Oregon Highway Plan analysis. All scenarios in this study used the same improvement dollars, and as such, the scenarios are relative to each other.
- Reflect improvements that are not modeled by program (i.e., bridges, intersection and interchange improvements).
- Reflect cost or benefits resulting from network impacts, such as induced demand from highway investment. Or
- Simulate the application of benefit-cost analysis at the project level.

This analysis does:

- Provide highway investment/performance benchmarks for planning and legislative consideration.
- Estimate the incremental impact of changes in highway conditions and performance resulting from investment initiatives. And
- Use benefit-cost analysis to provide the foundation for decision models at three levels: (1) project evaluation, (2) program definition, and (3) resource allocation among programs.

APPENDIX A: Acronym List

AADT	Average Annual Daily Traffic
AES	Average Effective Speed
AP	Highway Performance Monitoring System Analytical Process
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
CE	Construction Engineering (Expense for)
EXISTING	Conditions at the Beginning of Analysis, Defined as 1997
FHWA	Federal Highway Administration
FoB	Fair-or-Better Pavement Condition
HC	High Cost
HERS	Highway Economic Requirements System
HPMS	Highway Performance Monitoring System
MOD-HC	Preservation and Modernization Scenario with High Cost Improvements
MOD-RR	Preservation and Modernization Scenario with Region Restricted Improvements
MTC	Minimum Tolerable Conditions
NHS	National Highway System
ODOT	Oregon Department of Transportation
OHP	1999 Oregon Highway Plan
PE	Preliminary Engineering (Expense for)
PMS	Pavement Management System
PRES	Preservation Only Scenario
PSR	Present Serviceability Rating
RR	Region Restricted
R/W	Right-of-Way (Expense for)
SCS	Statewide Classification System
STIP	Statewide Transportation Improvement Program
UC	User Cost per Mile
VMT	Annual Vehicle Miles Traveled
VC	Volume-to-Capacity Ratio
ZERO	No Improvements