chapter 10

Sensitivity Analysis

Highway Sensitivity Analysis

Sound practice in modeling includes analyzing the sensitivity of key results to changes in assumptions. For the Maintain Conditions and Performance scenario and the Improve Conditions and Performance scenario presented in Chapter 8, this section analyzes how changes in some of the underlying assumptions would affect the estimate of the average annual requirement for highway investment. First to be varied are economic assumptions about the

- Values of traveler time savings and traveler safety,
- Discount rate used to convert future costs and benefits into present-value equivalents,
- Costs of the types of capital improvements modeled,
- Projections for the price of motor fuel, and
- Projected growth in aggregate traffic volumes.

Conducted only within the Highway Economic Requirements System (HERS) are the tests that vary the growth rates assumed for the value of travel time savings and the price of motor fuel; growth in these factors is absent from National Bridge Investment Analysis System (NBIAS) and is presumed to have minor effects on the bridge investment needs within that model's scope—repair, rehabilitation, and functional improvements.

Next varied are the investment strategies assumed in HERS for future deployment of Operations/Intelligent Transportation System (ITS). A subsequent section within this chapter explores information regarding the assumptions underlying the analyses developed using the Transit Economic Requirements Model (TERM).

An important outcome of the HERS results is that, under both baseline and sensitivity test assumptions, the Maintain Conditions and Performance is equivalent to a scenario in which the metric to be maintained is simply average pavement roughness. As defined, the Maintain Conditions and Performance sets HERS-related spending at the lowest level at which the 2032 projections for each of two measures—the average International Roughness Index (IRI) and average delay per vehicle miles traveled (VMT)—indicate conditions and performance that match or surpass those in the 2012 base year. In each of this report's simulations of this scenario, however, the binding constraint was maintaining average IRI. (The level of HERS-related spending that just sufficed to meet this constraint resulted in a decrease in average delay per VMT below the level in 2012.) For this reason, and because travel time delay depends much more on highway capacity than on pavement condition, any change to HERS assumptions that causes the model to reduce the share of spending for system expansion projects also will decrease the HERS component of spending in the Maintain Conditions and Performance scenario (and conversely).

Alternative Economic Analysis Assumptions

For application in benefit-cost analyses of programs and actions under their purview, the U.S. Department of Transportation (DOT) periodically issues guidance on valuing changes in travel time and traveler safety, and the Office of Management and Budget (OMB) provides guidance on the discount rate. Recognizing the uncertainty regarding these values, the guidance documents include both specific recommended values and ranges of values to be tested. The analyses presented in Chapters 7 and 8 of this report are based on the primary recommendations in DOT and OMB guidance for these economic inputs, whereas the analyses presented in this chapter rely on recommended alternative values to be used for sensitivity testing.

For the HERS analyses presented in Chapters 7 and 8, fuel price projections incorporate the "Reference Case" forecasts from the U.S. Department of Energy's *Annual Energy Outlook* (AEO). The AEO presents a range of potential alternative forecasts. One such alternative assuming lower fuel prices is explored in this section.

Value of Travel Time Savings

The value of travel time savings is a critical component of benefit-cost analysis of transportation investments, often the largest component of the estimated benefits. For HERS and NBIAS, the Federal Highway Administration (FHWA) estimates average values of time savings by vehicle hour traveled by vehicle type. Primarily, these values reflect the benefits from savings in the time travelers spend in vehicles, taking into account that vehicles can have multiple occupants. Time used for travel represents a cost to society and the economy because that time could be used for other more enjoyable or productive purposes. For heavy trucks, the FHWA makes additional allowances for the benefits from freight's arriving at its destination faster and from the opportunities for more intensive vehicle utilization when trips can be accomplished in less time. Even for these types of vehicles, however, the value of travel time savings estimated by FHWA primarily reflects the benefits from the freeing of travelers' time—the time of the truck driver and other vehicle occupants.

For valuation of traveler time, the analysis in this report follows, essentially, DOT's guidance on valuing travel time saved in 2012 (https://www.transportation.gov/office-policy/transportation-policy/guidance-value-time). In the analyses presented in Chapters 7 and 8, traveler time savings are valued per person hour at $12.30 for personal travel and between $27 and $32 for business travel. The value for personal travel is set in the guidance at 50 percent of hourly household income calculated as median annual household income divided by 2,080, the annual work hours of someone working 40 hours every week. The values for business travel are set at the relevant estimate of average hourly labor compensation (wages plus supplements). The variation in these values by vehicle type indicates, for example, that truck drivers typically earn less than business travelers in light-duty vehicles. (For details on the derivation of these values, see Appendix A.)

These values per person hour of travel are estimates subject to considerable uncertainty. Even when personal and business travel purposes are distinguished, estimating an average value of travel time is complicated by substantial variation in the value of travel time among individuals and, even for a given individual, among trips. Contributing to such variation are differences in incomes, employment status and earnings, attitudes, conditions of travel (e.g., the level of traffic congestion), and other factors. Moreover, studies that estimate values of travel time often are difficult to compare because of differences in data and methodology.

In view of the resulting uncertainty, DOT guidance calls for sensitivity tests that set values of travel time lower or higher than for the baseline. For personal travel time, these values are 35 percent and 60 percent of median hourly household income, rather than 50 percent as assumed in the baseline. For business travel time, these values are 80 percent and 120 percent of average hourly labor compensation, rather than the baseline assumption of 100 percent.

Exhibit 10-1 shows the effects of these variations on spending levels in the two scenarios reexamined in this chapter. For the NBIAS-derived component of spending, the effects are very small (well under 1.0 percent), consistent with bridge capacity expansion being outside the model's scope. Except where they would eliminate long detours caused by vehicle weight restrictions on a bridge, the bridge preservation actions evaluated by NBIAS would have minimal effects on travel times.

Exhibit 10-1 Impact of Alternative Value of Time Assumptions on Highway Investment Scenario Average Annual Investment Levels

Alternative Time Valuation Assumptions for Personal and Business Travel as Percentage of Hourly Earnings	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Baseline[1] (Personal–50%; Business–100%)	**$89.9**		**$142.5**	
HERS-Derived Component	$50.9		$75.4	
NBIAS-Derived Component	$12.2		$24.6	
Other (Nonmodeled) Component	$26.9		$42.6	
Lower (Personal–35%; Business–80%)	**$84.7**	**-5.8%**	**$134.6**	**-5.6%**
HERS-Derived Component	$47.3	-7.0%	$69.8	-7.4%
NBIAS-Derived Component	$12.1	-0.6%	$24.6	0.0%
Other (Nonmodeled) Component	$25.3	-5.8%	$40.2	-5.6%
Higher (Personal–60%; Business–120%)	**$92.7**	**3.1%**	**$147.7**	**3.6%**
HERS-Derived Component	$52.8	3.8%	$78.9	4.7%
NBIAS-Derived Component	$12.2	0.2%	$24.7	0.3%
Other (Nonmodeled) Component	$27.7	3.1%	$44.1	3.6%

[1] The baseline levels shown correspond to the systemwide scenarios presented in Chapter 8. The investment levels shown are average annual values for the period from 2013 through 2032.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

For the HERS-derived component of spending, the percentage reductions with lower values of traveler time are slightly over 7 percent in both scenarios, but the explanations differ. In the Improve Conditions and Performance scenario, the goal is to exploit all opportunities for cost-beneficial investments, which become fewer when the travel time savings are valued less. In the Maintain Conditions and Performance scenario, valuing travel time savings less increases the share of spending that HERS allocates to capacity expansion, making funds available for the system preservation improvements that reduce pavement roughness. For this reason, and because the binding constraint in this scenario is maintaining average pavement roughness, the required level of HERS-related spending decreases. Conversely, that spending increases when the higher values of time are assumed, by 3–4 percent in both scenarios.

Nonmodeled Highway Investments

The HERS-derived component of each scenario represents spending on pavement rehabilitation and capacity expansion on Federal-aid highways. The NBIAS-derived component represents rehabilitation spending on all bridges, including those off the Federal-aid highways. The nonmodeled component corresponds to system enhancement spending, plus pavement rehabilitation and capacity expansion on roads not classified as Federal-aid highways.

In the Sustain 2012 Spending scenario presented in Chapter 8, the values for these HERS and NBIAS components sum to $73.8 billion. In 2012, nonmodeled spending accounted for 29.9 percent of total investment ($31.4 billion of $105.2 billion) and is assumed to form the same share in all scenarios presented in Chapter 8.

Likewise, for the sensitivity analysis for the Maintain Condition and Performance and the Improve Condition and Performance scenarios presented in this section, the nonmodeled component is set at 29.9 percent of the total investment level. As the combined levels of the HERS-derived and NBIAS-derived scenario components increase or decrease, the nonmodeled component changes proportionally. Consequently, the percentage change in the nonmodeled component of each alternative scenario relative to the baseline always matches the percent change in the total investment level for that scenario.

Growth in the Value of Time

The opportunity cost of time spent traveling generally increases when real earnings or real incomes increase. Higher hourly pay usually reflects an increase in the value that an hour of labor contributes to production, and hence in the value of an hour of travel time saved on the job. On higher incomes, people are more able, and hence more willing, to pay for savings in personal travel time.

In addition, the long-term trend in U.S. economic history is for real growth over time in both average household incomes and average hourly earnings. In factoring this trend into its guidance on the value of travel time savings in benefit-cost analysis, DOT assumes that such growth will occur in the future at 1.2 percent per year (based on Congressional Budget Office projections for real median household income) and that the average value of travel time savings will increase at the same rate. In this report, these assumptions are built into the baseline analyses with HERS that are presented in Chapters 7 and 8.

Exhibit 10-2 shows the results of sensitivity tests with HERS that assume zero future growth in the value of travel time and, alternatively, 2.4 percent growth. Qualitatively, the results are the same as in the sensitivity test that changed the base-year value of travel time, and the explanations are also the same. Quantitatively, relative to the baseline assumption of 1.2 percent growth, assuming zero future growth in the value of time reduces the scenario investment levels by about 4 percent, and assuming higher values of time increases the scenario investment levels by about 3 percent.

The modeled changes in future economic growth also could shift future demand for highway travel, which in turn would affect the investment levels in this report’s scenarios, but these shifts are not reflected in the present analysis. In theory, the direction of these shifts is ambiguous. Although affluence tends to generate demand for travel, higher wage levels increase the opportunity cost of time spent traveling rather than at the workplace, which could dampen the demand for highway travel. Similarly, higher household incomes could generate demands for uses of time that compete with personal travel—for example, with the additional money, someone might purchase video games that incline them to spend more time at home rather than engaging in outside pursuits that require travel. Although a preliminary literature review that FHWA has undertaken suggests that increasing affluence will increase demand for highway travel overall, further investigation is needed to confirm and quantify this effect; this research is among the priorities for the HERS program.

Exhibit 10-2 Impact of Alternative Assumptions About Growth in the Real Value of Time on Highway Investment Scenario Average Annual Investment Levels

	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
Alternative Value of Time Growth Assumptions	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Baseline[1] (1.2%-increase per year)	$89.9		$142.5	
HERS-Derived Component	$50.9		$75.4	
Lower (0.0%-increase per year)	$86.5	-3.8%	$136.3	-4.4%
HERS-Derived Component	$48.5	-4.7%	$71.0	-5.8%
Higher (2.4%-increase per year)	$92.6	3.1%	$146.3	2.6%
HERS-Derived Component	$52.8	3.8%	$78.0	3.5%

[1] The baseline levels shown correspond to the systemwide scenarios presented in Chapter 8. The investment levels shown are average annual values for the period from 2013 through 2032.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Value of Traveler Safety

One of the most challenging questions in benefit-cost analysis is what monetary cost to place on injuries of various severities. Few people would consider any amount of money to be adequate compensation for a person's being seriously injured, much less killed. On the other hand, people can attach a value to changes in their risk of suffering an injury, and indeed such valuations are implicit in their everyday choices. For example, a traveler may face a choice between two travel options that are equivalent except that one carries a lower risk of fatal injury but costs more. If the additional cost is $1, a traveler who selects the safer option is manifestly willing to pay at least $1 for the added safety—what economists call "revealed preference." Moreover, if the difference in risk is, say, one in a million, then a million travelers who select the safer option are collectively willing to pay at least $1 million for a risk reduction that statistically can be expected to save one of their lives. In this sense, the "value of a statistical life" among this population is at least $1 million.

Based on the results of various studies of individual choices involving money versus safety tradeoffs, some government agencies estimate an average value of a statistical life for use in their regulatory and investment analyses. Although agencies generally base their estimates on a synthesis of evidence from various studies, the decision as to which value is most representative is never clear-cut, thus warranting sensitivity analysis. DOT issued guidance in 2013 recommending a value of $9.1 million for analyses with a base year of 2012, as is the case in this C&P report (https://www.transportation.gov/office-policy/transportation-policy/guidance-treatment-economic-value-statistical-life). The guidance also required that regulatory and investment analyses include sensitivity tests using alternative values of $5.2 million as the lower bound and $12.9 million for the upper bound. For nonfatal injuries, the guidance sets values per statistical injury as percentages of the value of a statistical life; these vary according to the level of severity, from 0.3 percent for a "minor" injury to 59.3 percent for a "critical" injury. (The injury levels are from the Abbreviated Injury Scale.)

Impact of Alternatives on HERS Results

HERS contains equations for each highway functional class to predict crash rates per VMT and parameters to determine the number of fatalities and nonfatal injuries per crash. The model assigns to crashes involving fatalities and other injuries an average cost consistent with DOT guidance, including the use of alternative values for sensitivity tests. As shown in *Exhibit 10-3*, the sensitivity tests reveal only minor impacts on the average annual requirement for HERS-related investment; relative to a baseline in which the value of a statistical life is set at $9.1 million, increasing or decreasing that value by about $3.8 million alters the estimated investment requirement by well under 1 percent in each case. One reason for this insensitivity is that crash costs are estimated in HERS to form a small share of total highway user costs (14.0 percent in 2012). In addition, as Chapter 7 revealed, the crash costs are much less sensitive than travel time and vehicle operating costs to changes in the level of total investment within the scope of HERS. (Data limitations preclude that scope from including highway improvements that primarily address safety issues.)

Exhibit 10-3 Impact of Alternative Value of Life Assumptions on Highway Investment Scenario Average Annual Investment Levels

	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
Alternative Value of Statistical Life Assumptions (2012 Dollars)	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Baseline[1] ($9.1 Million)	**$89.9**		**$142.5**	
HERS-Derived Component	$50.9		$75.4	
NBIAS-Derived Component	$12.2		$24.6	
Other (Nonmodeled) Component	$26.9		$42.6	
Lower ($5.2 Million)	**$89.0**	**-1.0%**	**$138.3**	**-3.0%**
HERS-Derived Component	$50.6	-0.5%	$74.9	-0.6%
NBIAS-Derived Component	$11.8	-3.1%	$22.1	-10.2%
Other (Nonmodeled) Component	$26.6	-1.0%	$41.3	-3.0%
Higher ($12.9 Million)	**$90.6**	**0.8%**	**$144.2**	**1.2%**
HERS-Derived Component	$51.2	0.7%	$75.8	0.6%
NBIAS-Derived Component	$12.3	1.2%	$25.3	3.0%
Other (Nonmodeled) Component	$27.1	0.8%	$43.1	1.2%

[1] The baseline levels shown correspond to the systemwide scenarios presented in Chapter 8. The investment levels shown are average annual values for the period from 2013 through 2032.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Impact of Alternatives on NBIAS Results

Changes in the valuation of traveler safety affect the NBIAS-derived component of the scenario investment levels more significantly. In *Exhibit 10-3*, reducing the assumed value of a statistical life from the baseline of $9.1 million to $5.2 million decreases the estimate of investment needed for bridge repair, rehabilitation, and functional improvement by 3.1 percent in the Maintain Conditions and Performance scenario and by 10.9 percent in the Improve Conditions and Performance scenario. In comparison with these decreases, the estimated percentage increases in NBIAS-related investment when the assumed value of a statistical life increases by about the same amount above the baseline (from $9.1 million to $12.9 million) are less than half as large.

Discount Rate

Benefit-cost analyses use a discount rate that weighs benefits and costs expected to arise farther in the future less than those that would arise sooner. Thus far, in this report's applications of HERS, NBIAS, and TERM have set the discount rate at 7 percent; this means that deferring a benefit or cost for a year reduces its real value by approximately 6.5 percent (1/1.07). This choice of real discount rate conforms to the "default position" in the 1992 OMB guidance on discount rates, in Circular A-94, for benefit-cost analyses of Federal programs or policies. Subsequently, in 2003, OMB's Circular A-4 recommended that regulatory analyses use both 3 percent and 7 percent as alternative discount rates (http://www.whitehouse.gov/sites/default/files/omb/assets/omb/circulars/a004/a-4.pdf). The justifications for these recommendations apply equally to benefit-cost analyses of public investments, so the sensitivity tests in this section include the use of the 3-percent discount rate as an alternative to the 7-percent rate used in the baseline simulations.

Q&A Could the discount rate be higher than 7 percent?

The 2003 OMB guidance calls for using a discount rate higher than 7 percent as a further sensitivity test in some instances. In the context of public investment, this recommendation applies when the likelihood is that (1) the investment's opportunity cost will consist largely of displaced private investment, and (2) the displaced investment would have generated an average real rate of return exceeding 7 percent annually. Although the first of these conditions could be valid for some public investments in highways and transit systems, that displaced private investments will average rates of return above 7 percent annually could be difficult to justify. In 2003, OMB referred to its own recent estimate that the average real rate of return on private investment remained near the 7 percent level that OMB estimated in 1992. Although OMB noted that the average real rate of return on corporate capital in the United States was approximately 10 percent in the 1990s, whether the current economic outlook could justify the expectation of a rate of return averaging above 7 percent during this report's analysis period is by no means clear.

For infrastructure improvements, including those that HERS and NBIAS consider, the normal sequence is for an initial period in which net benefits are negative, reflecting the costs of construction, followed by many years of positive net benefits, reflecting the benefits of improved infrastructure in place. Because the positive net benefits materialize farther in the future than the costs of construction, a reduction in the discount rate increases the weight attached to the positive net benefits relative to the construction costs, resulting in a higher benefit-cost ratio. Moreover, with all potential projects now having a higher benefit-cost ratio, when the investment objective is to exhaust all opportunities for implementing cost-beneficial projects, the indicated amount of investment will increase. Accordingly, *Exhibit 10-4* shows that in the Improve Conditions and Performance scenario, a reduction in the assumed annual discount rate from 7 percent to 3 percent increases the total level of investment by 20.3 percent, and the HERS and NBIAS components by a similar percentage.

Exhibit 10-4 Impact of Alternative Discount Rate Assumption on Highway Investment Scenario Average Annual Investment Levels

Alternative Assumptions About Discount Rate	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Baseline[1] (7% discount rate)	**$89.9**		**$142.5**	
HERS-Derived Component	$50.9		$75.4	
NBIAS-Derived Component	$12.2		$24.6	
Other (Nonmodeled) Component	$26.9		$42.6	
Alternative (3% discount rate)	**$88.0**	**-2.1%**	**$171.5**	**20.3%**
HERS-Derived Component	$50.4	-0.9%	$90.8	20.5%
NBIAS-Derived Component	$11.3	-7.0%	$29.5	19.8%
Other (Nonmodeled) Component	$26.3	-2.1%	$51.2	20.3%

[1] The baseline levels shown correspond to the systemwide scenarios presented in Chapter 8. The investment levels shown are average annual values for the period from 2013 through 2032.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

For the Maintain Conditions and Performance scenario, the reduction in the discount rate has more complex effects within the models. At any given level of HERS-related spending, the model determines that allocating a slightly higher share to system preservation projects would be cost-beneficial; this is because, in HERS, benefits arising relatively late in the project life cycle tend to be more important for system rehabilitation than for system expansion projects. Because the preservation share of spending increases, the $50.9 billion of spending from the baseline (7-percent discount rate) would more than suffice to maintain IRI at the base-year level. Thus, a reduction in the discount rate leads the model to slightly reduce spending in the Maintain Conditions and Performance scenario.

The NBIAS-derived component of spending in the Maintain Conditions and Performance scenario is much more sensitive to the discount rate. Reducing the discount rate from 7 percent to 3 percent causes this component to decrease by 7.0 percent.

Costs of Capital Improvements

The HERS database includes a cost matrix that indicates typical cost for each type of modeled improvement. For example, the current matrix indicates that in 2012, reconstructing and widening a lane of rural Interstate highway typically cost $3,180 per lane mile. The matrix is periodically updated—the most recent full update, which obtained cost data from a survey of projects, produced estimates for 2002. These estimates have since been updated by simply using a general highway construction cost index. Applying the same general index to all types of improvements ignores changes that might have occurred in the relative costs of different types of projects.

Even for updating the overall level of improvement costs, the indexing approach has been problematic because of challenges in splicing together the FHWA Composite Bid Price Index and its successor, the National Highway Construction Cost Index. During the period in which they overlapped, 2002–2006, quality and coverage of the supporting data were deteriorating for the Bid Price Index and improving for the Construction Cost Index. To splice these series together for the C&P reports, FHWA chose 2006 as the year to switch to the Construction Index. This choice is arguable, however, and the selection of a different year could have made a material difference, given the significant divergences in movements of the two indices during the overlap years. The period under consideration was one of marked volatility in highway construction costs, so the divergences could owe in part to challenges in measuring costs when they are fluctuating sharply. (For further discussion of this issue, see Chapter 10 of the 2010 C&P Report.) FHWA is currently conducting a study to update the HERS improvement cost matrix using project-level data.

Furthermore, even without the complications from switchover between indices, simple inflation adjustments are inadequate to reflect many factors that have changed since 2002. These factors include changes in the construction materials typically used, greater reliance of off-peak or night work (with resulting higher labor costs), and changes in the nature of typical reconstruction projects. (In particular, as the system ages, reconstruction projects more frequently require replacement through the sub-base).

The uncertainty that such problems introduce into the base-year estimates of improvement warrants sensitivity testing. This is also true of the base-year improvement costs in NBIAS, which could be too low. *Exhibit 10-5* shows the sensitivity of the HERS and NBIAS results to increasing all

Exhibit 10-5 Impact of an Increase in Capital Costs on Highway Investment Scenario Average Annual Investment Levels

Alternative Assumptions Regarding Unit Costs for Capital Improvements	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Baseline[1]	**$89.9**		**$142.5**	
HERS-Derived Component	$50.9		$75.4	
NBIAS-Derived Component	$12.2		$24.6	
Other (Nonmodeled) Component	$26.9		$42.6	
Alternative (25% above baseline)	**$108.0**	**20.2%**	**$145.9**	**2.3%**
HERS-Derived Component	$62.8	23.5%	$77.6	3.0%
NBIAS-Derived Component	$13.0	6.6%	$24.7	0.3%
Other (Nonmodeled) Component	$32.3	20.2%	$43.6	2.3%

[1] The baseline levels shown correspond to the systemwide scenarios presented in Chapter 8. The investment levels shown are average annual values for the period from 2013 through 2032.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

base-year capital improvement costs by 25 percent. In the Improve Conditions and Performance scenario, the increase in the estimate of required spending is 3.0 percent for the HERS component and 0.3 percent for the NBIAS component, far smaller than the assumed 25-percent increase in unit improvement costs. This is because the target of the Improvement Conditions and Performance scenario is to implement all cost-beneficial improvements, and an increase in improvement costs reduces the pool of projects that pass a benefit-cost test. The reduction in this pool nearly offsets the direct effect of the cost increase on the scenario's requirement for investment spending.

In the Maintain Conditions and Performance scenario, the sensitivity test yields notably different results between HERS and NBIAS. The required level of HERS-related spending, 23.5 percent, nearly matches the assumed 25-percent increase in unit improvement costs, as expected: Meeting the scenario's goal of keeping average pavement roughness unchanged requires a similar scale of improvement, regardless of cost. In contrast, the estimate of the NBIAS-derived component of spending increases by only 6.6 percent because the model shifts a large amount of spending on bridge replacement to more cost-beneficial bridge maintenance projects. This substitution occurs because, when the costs of improving bridges rise, benefit-cost analysis more strongly influences the model's project selection decisions, leading to the rejection of some aggressive bridge replacement projects that have low benefit-cost ratios. The sharper focus on benefit-cost ratio reduces the estimate of the total spending required to maintain conditions and performance, and this substantially offsets the direct effect of the modeled 25-percent increase in improvement costs.

Motor Fuel Prices

The projections of motor fuel prices in this report's baseline analysis conform to those in the Reference case of the 2014 AEO, released by the U.S. Energy Information Administration. The 2014 release was the most current available when the data inputs to the modeling in this report were being prepared. AEO projections for prices of motor fuel and other energy products are constant-dollar, or "real," measures that show changes after adjusting for general inflation. For this report's analysis period, 2013–2032, the Reference case projections indicated average retail prices of gasoline significantly below the 2012 level for the first decade and then substantially recovering; the projections for 2022 and 2032 are 14.1 percent and 4.9 percent higher than the 2012 level.

In addition to the Reference case, the AEO includes alternative cases that explore important areas of uncertainty for markets, technologies, and policies in the U.S. energy economy. For the Low Oil Price case, the 2014 AEO projects low oil prices resulting from a combination of low demand for petroleum and other liquids in developing economies and higher global supply. Gasoline prices projected for 2022 and 2032 are each about 30 percent below the 2012 level.

The Low Oil Price case has projected motor fuel prices more accurately than the Reference case to date: For 2015, the average real price per gallon of gasoline (2012 dollars, Consumer Price Index-deflated) was $2.35, much closer to the $2.63 projected in the Low Oil Price case than the $3.12 projected in the Reference case. Past experience has shown, however, that motor fuel and other energy prices are volatile and hard to predict, so this result does not indicate future relative performance of the fuel price projections over the entire two decades for which this report projects highway conditions and performance.

Broader Sensitivity Test of Economic Assumptions Related to Oil Prices

The sensitivity tests presented here for motor fuel prices omit various indirect impacts. Lower fuel prices reduce the importance consumers attach to fuel economy in vehicle purchase decisions, which gradually reduces average fuel economy by changing the composition of the vehicle fleet. More immediately, travelers will adjust to lower fuel prices in other ways that reduce fuel economy. In particular, those with more than one vehicle at their disposal (as in multi-vehicle households) will tend to use the less fuel-efficient vehicles more intensively. These responses will also affect vehicle miles traveled, but in ways more complex than the HERS model can adequately represent at present.

In addition to these responses, the sensitivity tests for motor fuel prices omit consideration of the differences between the two AEO cases in macroeconomic outcomes. For real GDP, the average annual growth rate projected over 2012–2040 is 0.5 percent higher in the Low Oil Price case than in the Reference case (2.4 percent versus 1.9 percent), and higher growth will increase vehicle miles traveled as well as the value of travel time savings. Although other sensitivity tests presented in the chapter treat uncertainty in both vehicle miles traveled and the value of travel time, future C&P reports could examine the overall effects of incorporating into HERS the AEO projections for the High or Low Oil Price alternatives to the Reference case.

Replacing the Reference case projections for gasoline and diesel fuel prices with those from the Low Oil Price case increases the HERS-derived component of spending by 1.4 percent in the Maintain Conditions and Performance scenario and 3.8 percent in the Improve Conditions and Performance scenario (*Exhibit 10-6*). This increase reflects partly that lower fuel prices stimulate travel demand. In the Maintain Conditions and Performance scenario, VMT in the final year of the analysis period, 2032, are projected to be 2.0 percent greater under the low fuel price assumptions than in the baseline.

Exhibit 10-6 Impact of Alternative Future Fuel Price Assumption on Highway Investment Scenario Average Annual Investment Levels

Alternative Assumptions About Future Fuel Prices	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Baseline[1] (AEO Reference Case)	**$89.9**		**$142.5**	
HERS-Derived Component	$50.9		$75.4	
Alternative (AEO Low Oil Price Case)	**$90.9**	**1.2%**	**$146.6**	**2.8%**
HERS-Derived Component	$51.6	1.4%	$78.2	3.8%

[1] The baseline levels shown correspond to the systemwide scenarios presented in Chapter 8. The investment levels shown are average annual values for the period from 2013 through 2032.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

In the Improve Conditions and Performance scenario, where the corresponding difference in VMT in 2032 is 2.1 percent, the increase in spending also reflects that in HERS, additional highway spending produces negative savings in fuel consumption per mile traveled. This is because the improvements funded out of the additional spending, particularly expansions of highway capacity, lead to increases in average travel speed, which in HERS, degrades fuel economy. Lower prices for motor fuel prices reduce the cost attached to this disbenefit, resulting in more improvements passing the benefit-cost test, and hence more spending in a scenario where all such improvements are funded. That said, the HERS equations for fuel and other vehicle operating costs are dated and are not altogether accurate in representing the effects of highway improvements on fuel economy; in particular, they make no allowance for the extra fuel consumption due to speed variability from congestion and incident delay. The FHWA is currently conducting a project to update and revamp these equations.

Traffic Growth Projections

In this report's baseline analyses, projections for traffic growth rates by vehicle class were taken from an econometric model for forecasting VMT. Chapter 7 described this model and its application in HERS and NBIAS. For 2013–2032, total VMT were projected to increase at an average annual rate of 1.04 percent in the baseline, and are projected to increase at lower and higher rates in the sensitivity tests (*Exhibit 10-7*). The lower rate, 0.74 percent, is the growth rate in the official projections for the U.S. resident population. The higher rates, 1.41 percent for the HERS simulations and 1.48 percent for the NBIAS simulations, derive from the projections of traffic volumes by highway section in the Highway Performance Monitoring System and by bridge in the National Bridge Inventory. The low and high growth rates for heavy trucks are based on the "pessimistic" and "optimistic" assumptions in the econometric forecasting model. As in the baseline projections, they exceed the growth rate projected for traffic overall, which means that light-duty vehicle traffic would grow at a rate below that for traffic overall.

Exhibit 10-7 Projected Average Percent Growth per Year in Vehicle Miles Traveled by Vehicle Class, 2013–2032

Vehicle Class	Baseline Growth Rate	Basis	Low-Growth Growth Rate	Basis	High-Growth Growth Rate	Basis
All Vehicles	1.04%	Econometric Model Forecast	0.74%	Equals Projected Population Growth Rate (U.S. Census)	1.41%	HPMS Section-level Traffic Projections, Aggregated
Single-Unit Trucks	2.15%	Econometric Model Forecast	1.26%	Econometric Model Forecast (Pessimistic Assumptions)	2.94%	Econometric Model Forecast (Optimistic Assumptions)
Combination Trucks	2.12%	Econometric Model Forecast	1.57%	Econometric Model Forecast (Pessimistic Assumptions)	2.67%	Econometric Model Forecast (Optimistic Assumptions)

Sources: FHWA National Vehicle Miles Traveled Projection; Highway Performance Monitoring System; U.S. Bureau of the Census

In both scenarios, assuming the lower traffic growth rates reduces the HERS-derived component of spending by about 12 percent, while assuming the higher traffic growth rates increases it about 15 percent (*Exhibit 10-8*). On the other hand, the NBIAS-derived component responds minimally to these changes in assumptions. This difference in sensitivity of results partly reflects a difference in benefit composition between the types of investment evaluated in HERS and NBIAS. In general, the benefits from the bridge improvements that NBIAS evaluates are predominantly savings in agency maintenance costs; unlike in HERS, savings in the user costs of travel are a small component. Also, the performance of many types of bridge elements is primarily influenced by age and environmental conditions rather than traffic volume.

Exhibit 10-8 Impact of Alternative Travel Growth Forecasts on Highway Investment Scenario Average Annual Investment Levels

Alternative Assumptions About Future Annual VMT Growth[1]	Maintain Conditions and Performance Scenario		Improve Conditions and Performance Scenario	
	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Baseline[2] (1.04% per year)	**$89.9**		**$142.5**	
HERS-Derived Component	$50.9		$75.4	
NBIAS-Derived Component	$12.2		$24.6	
Other (Nonmodeled) Component	$26.9		$42.6	
Lower (Tied to Projected Rate of Population Growth—0.74% per year)	**$81.3**	**-9.6%**	**$129.0**	**-9.5%**
HERS-Derived Component	$44.9	-11.7%	$66.0	-12.4%
NBIAS-Derived Component	$12.1	-0.5%	$24.5	-0.5%
Other (Nonmodeled) Component	$24.3	-9.6%	$38.6	-9.5%
Higher (Tied to State Forecasts—HPMS at 1.41% per year; NBI at 1.48% per year)	**$101.1**	**12.5%**	**$159.8**	**12.1%**
HERS-Derived Component	$58.6	15.2%	$87.2	15.7%
NBIAS-Derived Component	$12.3	1.3%	$24.9	1.1%
Other (Nonmodeled) Component	$30.2	12.5%	$47.8	12.1%

[1] The VMT growth rates identified represent the forecasts entered into the HERS and NBIAS models. The travel demand elasticity features in HERS modify these forecasts in response to changes in highway user costs resulting from future highway investment.

[2] The baseline levels shown correspond to the systemwide scenarios presented in Chapter 8. The investment levels shown are average annual values for the period from 2013 through 2032.

Sources: Highway Economic Requirements System and National Bridge Investment Analysis System.

Alternative Strategies

Sensitivity tests can be conducted with HERS and NBIAS not only for alternative technical assumptions, but also for selected policy alternatives. One such alternative pertains to accelerating the future rate of deployment of Operations/ITS strategies modeled in HERS.

Accelerating Operations/ITS Deployments

As described in Chapter 7, the HERS model considers the impacts on highway conditions and performance of various types of ITS and other operational enhancements to highways. Appendix A describes the types of strategies considered (including arterial management, freeway management, incident management, and traveler information systems) and three scenarios for future deployment. Although it incorporates assumptions about future deployment, HERS does not subject operational enhancements to benefit-cost analysis or to other economic evaluation; thus, the preceding chapters in this report referred to spending on these and other system enhancements as "nonmodeled." The only spending that HERS models in this sense is on highway pavement rehabilitation and capacity expansion, although spending on operational enhancements is represented.

In the Maintain Conditions and Performance scenario, annual spending on HERS-modeled improvements averaged $50.9 billion under the baseline assumptions about future deployment of operational improvements. If HERS-modeled spending were held at that level while future deployment of operational improvements were assumed to be more aggressive, overall conditions and performance in 2030 relative to 2010 would be improved rather than maintained. To attain the scenario goal, HERS-modeled spending must therefore be lower when the alternative deployment assumptions replace the baseline, which assumes continuation of existing deployment trends. The "aggressive" alternative adjusts the various triggers for deployment—for example, how congested a freeway has to be for ramp metering to be introduced—such that the rates of deployment are 30-60 percent higher than in the baseline. The other alternative considered would deploy all the operational improvements selected in the aggressive alternative "immediately" – i.e. in the first five years of the 20-year analysis period.

For the "aggressive" deployment alternative, *Exhibit 10-9* shows the HERS-modeled capital spending to average $49.3 billion per year and spending on operational enhancements (including capital, and operations and maintenance costs) to be $0.6 billion per year more than in the baseline. The sum of these figures, $49.9 billion, indicates a $1.0-billion decrease in total spending relative to the baseline value of $50.9 billion to achieve the objectives of the Maintain Conditions and Performance scenario. For the "full immediate deployment alternative," total spending is $49.8 billion, slightly lower than for the aggressive deployment alternative.

Exhibit 10-9 Impact of Alternative Operations Strategies Deployment Rate Assumptions on Selected Performance Indicators and Highway Investment Scenarios

	Average Annual Highway Investment, 2013 through 2032 (Billions of 2012 Dollars)			
	HERS-Derived Component			
Operations/ITS Deployments Assumption[1]	HERS Modeled Spending	Additional Deployment Spending[2]	Total HERS	Total
Maintain Conditions and Performance Scenario				
Baseline (continue existing trends)	**$50.9**	**N/A**	**$50.9**	**$89.9**
Aggressive deployments alternative	$49.3	$0.6	$49.9	$88.5
Full immediate deployments alternative	$39.7	$10.1	$49.8	$88.4
Improve Conditions and Performance Scenario				
Baseline (continue existing trends)	**$75.4**	**N/A**	**$75.4**	**$142.5**
Aggressive deployments alternative	$74.0	$0.6	$74.6	$141.5
Full immediate deployments alternative	$64.2	$10.1	$74.3	$141.0

[1] The analyses presented in this table assume one of the following: (1) existing trends in ITS deployments will continue for 20 years; (2) an aggressive pattern of deployment will occur over the next 20 years; or (3) all of the aggressive deployments will occur immediately rather than being spread out over 20 years. The costs associated with the more aggressive deployments were deducted from the budget available in HERS for pavement and widening investments.

[2] Amounts reflect additional capital and operation and maintenance costs associated with the alternative Operations/ITS deployment strategies relative to the baseline.

Source: Highway Economic Requirements System.

In the Improve Conditions and Performance scenario, more aggressive deployment of operational enhancements marginally reduces the amount of highway rehabilitation and capacity investment that HERS finds to be cost-beneficial. HERS-modeled rehabilitation and capacity investment decreases from $75.4 billion per year assuming baseline deployment to $74.6 billion per year assuming the aggressive deployment alternatives and to $74.3 billion assuming the full immediate deployment alternative. Notwithstanding the offsetting increases in spending for operational improvements, total average annual spending represented in HERS decreases by $0.8 billion if the aggressive deployment alternative replaces the baseline and by another $0.3 billion if the alternative changes from aggressive to full immediate deployment.

Transit Sensitivity Analysis

This section examines the sensitivity to key inputs of the estimates of transit investment needs that the Transit Economic Requirements Model (TERM) produces. The sensitivity of the estimates is evaluated in response to variations in the values of these key inputs:

- asset replacement timing (condition threshold),
- capital costs,
- value of time, and
- discount rate.

The alternative projections presented in this chapter assess how the estimates of baseline investment needs for the State of Good Repair (SGR) Benchmark and the Low-Growth and High-Growth scenarios discussed in Chapter 8 vary in response to changes in the assumed values of the input variables, above. Note that, by definition, funding under the Sustain 2012 Spending scenario does not vary with changes in any input variable, and thus this scenario is not considered in this sensitivity analysis.

Changes in Asset Replacement Timing (Condition Threshold)

Each of the four investment scenarios examined in Chapter 8 assumes that assets are replaced at condition rating 2.50 as determined by TERM's asset condition decay curves (in this context, 2.50 is referred to as the "replacement condition threshold"). Recall that TERM's condition rating scale runs from 5.0 for assets in "excellent" condition through 1.0 for assets in "poor" condition. In practice, this assumption implies replacement of assets within a short period (e.g., roughly 1 to 5 years, depending on asset type) of their having attained their expected useful lives. Replacement at condition 2.50 can therefore be thought of as providing a replacement schedule that is both realistic and potentially conservative. This replacement schedule is realistic because, in practice, few assets are replaced exactly at their expected useful life value due to many factors, including the time to plan, fund, and procure an asset replacement. It is a potentially conservative schedule because the needs estimates would be higher if all assets were to be replaced at precisely the end of their expected useful lives.

Exhibit 10-10 shows the effect of varying the replacement condition threshold by increments of 0.25 on TERM's projected asset preservation needs for the SGR Benchmark and the Low-Growth and High-Growth scenarios. Note that selection of a higher replacement condition threshold results in assets being replaced at a higher condition (i.e., at an earlier age). This, in turn, reduces the length of each asset's service life, thus increasing the number of replacements over any given period of analysis and driving up scenario costs. Reducing the replacement condition threshold would have the opposite effect. As shown in *Exhibit 10-10*, each of these three scenarios shows significant changes to total estimated preservation needs from quarter-point changes in the replacement condition threshold. Relatively small changes in the replacement condition threshold frequently translate into significant changes in the expected useful life of some asset types; hence, small changes can also drive significant changes in replacement timing and replacement costs.

Exhibit 10-10 Impact of Alternative Replacement Condition Thresholds on Transit Preservation Investment Needs by Scenario (Excludes Expansion Impacts)

	SGR Benchmark		Low-Growth Scenario		High-Growth Scenario	
Replacement Condition Thresholds	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Very late asset replacement (2.00)	$16.27	-4.3%	$15.73	-4.4%	$15.84	-4.2%
Replace assets later (2.25)	$16.57	-2.6%	$16.01	-2.6%	$16.10	-2.7%
Baseline (2.50)	$17.01		$16.44		$16.54	
Replace assets earlier (2.75)	$17.61	3.5%	$16.99	3.3%	$17.13	3.6%
Very early asset replacement (3.00)	$18.02	5.9%	$17.35	5.5%	$17.53	6.0%

Source: Transit Economic Requirements Model.

Changes in Capital Costs

The asset costs used in TERM are based on actual prices paid by agencies for capital purchases as reported to Federal Transit Administration (FTA) in the Transit Electronic Award Management (TEAM) System and in special surveys. Asset prices in the current version of TERM have been converted from the dollar-year replacement costs in which assets were reported to FTA by local agencies (which vary by agency and asset) to 2012 dollars using the RSMeans© construction cost index. Given the uncertain nature of capital costs, a sensitivity analysis has been performed to examine the effect that higher capital costs would have on the dollar value of TERM's baseline projected transit investment.

As *Exhibit 10-11* shows, TERM projects that a 25-percent increase in capital costs (i.e., beyond the 2012 level used for this C&P report) would be fully reflected in the SGR Benchmark, but only partially realized under the Low-Growth or High-Growth scenarios. This difference in sensitivity results is driven by the fact that investments are not subject to TERM's benefit-cost ratio in computing the SGR Benchmark (i.e., increasing costs has no consequences), whereas the two cost-constrained scenarios do employ this test. Hence, for the Low-Growth or High-Growth scenarios, any increase in capital costs (without a similar increase in the value of transit benefits) results in lower benefit-cost ratios and the failure of some investments to pass this test. Therefore, for these latter two scenarios, a 25-percent increase in capital costs would yield a roughly 13- to 15-percent increase in needs that pass TERM's benefit-cost test.

Exhibit 10-11 Impact of Increase in Capital Costs on Transit Investment Estimates by Scenario

Capital Cost Increases	SGR Benchmark		Low-Growth Scenario		High-Growth Scenario	
	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Baseline (no change)	$17.01		$22.88		$26.42	
Increase Costs 25%	$21.27	25.0%	$26.48	15.7%	$29.90	13.2%

Source: Transit Economic Requirements Model.

Changes in the Value of Time

The most significant source of transit investment benefits, as assessed by TERM's benefit-cost analysis, is the net cost savings to users of transit services, a key component of which is the value of travel time savings. Therefore, the per-hour value of travel time for transit riders is a key model input and a key driver of total investment benefits for those scenarios that use TERM's benefit-cost test. Readers interested in learning more about the measurement and use of the value of time for the benefit-cost analyses that TERM, the Highway Economic Requirements System, and the National Bridge Investment Analysis System perform should refer to the related discussion presented earlier in the highway section of this chapter.

For this C&P report, the Low-Growth and High-Growth scenarios are the only scenarios with investment needs estimates that are sensitive to changes in the benefit-cost ratio. (Note that the Sustain 2012 Spending scenario uses TERM's estimated benefit-cost ratios to allocate fixed levels of funding to preferred investments, while the computation of the SGR Benchmark does not.)

Exhibit 10-12 shows the effect of varying the value of time on the needs estimates of the Low-Growth and High-Growth scenarios. The baseline value of time for transit users is currently $12.50 per hour, based on Department of Transportation guidance. TERM applies this amount to all in-vehicle travel, but then doubles it to $25.00 per hour when accounting for out-of-vehicle travel time, including time spent waiting at transit stops and stations.

Given that value of time is a key driver of total investment benefits, changes in this variable lead to changes in investment ranging from an increase of roughly 7 percent to a decrease of 13 percent. The resulting different magnitudes of percent changes is because the absolute value of the changes from the baseline differ ($6.25 is a 50-percent change from baseline and $25 is a 100-percent change from baseline). In addition to this issue, we observe that the High-Growth scenario appears to be more sensitive to the value of time than the Low-Growth scenario. This is because the High-Growth scenario is associated with higher investment levels than is the Low-Growth scenario; therefore, any changes in the value of time will be magnified accordingly.

Exhibit 10-12 Impact of Alternative Value of Time Rates on Transit Investment Estimates by Scenario

Changes in Value of Time	Low-Growth Scenario		High-Growth Scenario	
	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
Reduce 50% ($6.25)	$20.21	-11.7%	$22.99	-13.0%
Baseline ($12.50)	$22.88		$26.42	
Increase 100% ($25.00)	$23.84	4.2%	$28.14	6.5%

Source: Transit Economic Requirements Model.

Changes to the Discount Rate

Finally, TERM's benefit-cost module uses a discount rate of 7 percent in accordance with guidance provided by the White House Office of Management and Budget. Readers interested in learning more about the selection and use of discount rates for the benefit-cost analyses that TERM, the Highway Economic Requirements System, and the National Bridge Investment Analysis System perform should refer to the related discussion presented earlier in the highway section of this chapter. For this sensitivity analysis and for consistency with the discussion above on Highway Economic Requirements System and National Bridge Investment Analysis System discount rate sensitivity, TERM's needs estimates for the Low-Growth and High-Growth scenarios were reestimated using a 3-percent discount rate. The results of this analysis are presented in *Exhibit 10-13*. These results show that this approximately 57-percent reduction in the discount rate leads to a range in total investment needs (or changes in the proportion of needs passing TERM's benefit-cost test) of a greater than 17-percent increase to a less than 1-percent decrease.

Under this sensitivity test, investment needs are usually higher for the lower (3 percent) discount rate as compared to the higher base rate (7 percent). This means that use of the lower rate allows more investments to pass TERM's benefit cost test. This situation is primarily the result of differences in the timing of the flows of benefits vs costs for the underlying scenario. Specifically, this test has based off of a fully (financially) unconstrained scenario that completely eliminates the large investment backlog at the start of the period of analysis and then invests incrementally as needed at a much lower rate to maintain this "perfect state of good repair" for the remaining 20 years of analysis. In contrast, investment benefits tend to be more evenly distributed throughout the 20-year period of analysis. So, with a high proportion of costs concentrated very early in the period of analysis and evenly distributed benefits, the ratio of discounted benefits to discounted costs tends to decline as the discount rate increases.

Exhibit 10-13 Impact of Alternative Discount Rates on Transit Investment Estimates by Scenario

Discount Rates	Low-Growth Scenario		High-Growth Scenario	
	Billions of 2012 Dollars	Percent Change From Baseline	Billions of 2012 Dollars	Percent Change From Baseline
7% (Baseline)	$22.88		$26.42	
3%	$22.85	-0.2%	$30.95	17.2%

Source: Transit Economic Requirements Model.