Chapter 10

Sensitivity Analysis

Summary

This chapter explores the effects of varying some of the assumptions that were used to develop the investment requirement projections in Chapter 7. In any modeling effort, evaluating the validity of the underlying assumptions is critical. The results produced by the Highway Economic Requirements System (HERS) and the Transit Economic Requirements Model (TERM) are strongly affected by the values they are supplied for certain key variables. This chapter was first added to the 1999 C&P report to open up more of the modeling process and to make the report more useful for supplementary analysis efforts.

There is a great deal of uncertainty about the appropriate values for the 20-year travel growth rates on which HERS and TERM rely. The highway and transit sections both show the impact that changing these assumptions would have on the investment requirement projections. Alternative estimates of highway investment requirements are shown for scenarios in which future highway travel growth rates match those observed over the last 20 years and for scenarios in which travel growth is substantially lower than that projected in the Highway Performance Monitoring System (HPMS) sample data. The sensitivity of the estimated transit investment requirements to the growth rate forecast is analyzed by allowing three alternative growth rate inputs: 50 percent higher than the forecast, 50 percent below the forecast, and 100 percent below the forecast (i.e., zero transit passenger mile growth).

The chapter also includes other sensitivity analyses showing the impact of using alternative values for certain key model parameters (whose estimated values may be subject to some uncertainty). Both the highway and transit sections analyze the impact of increasing the unit improvement costs in HERS and TERM by 25 percent and the effects of variations in the value of time. The highway section also considers alternative values for additional parameters, including the value of a statistical life, truck shares, and travel demand elasticity.

Highway Sensitivity Analysis

The accuracy of the investment requirements reported in Chapter 7 depends on the validity of the underlying assumptions used to develop the analysis. This section explores the effects that varying several key assumptions in the highway investment requirement analytical process would have on the Cost to Improve Highways and Bridges and the Cost to Maintain Highways and Bridges. While not discussed directly in this chapter, any changes in the projected investment requirements would also affect the gaps identified in Chapter 8 between projected spending and the investment requirement scenarios.

Alternative Travel Growth Assumptions

States provide forecasts of future vehicle miles traveled (VMT) for each individual Highway Performance Monitoring System (HPMS) sample highway section. As indicated in Chapter 7, the Highway Economic Requirements System (HERS) assumes that the forecast for each sample highway segment represents the level of travel that will occur if a constant level of service is maintained on the facility. This implies that VMT will only occur at this level if pavement and capacity improvements made on the segment over the 20-year analysis period are sufficient to maintain highway-user costs at 2000 levels. If HERS predicts that highway-user costs will deviate from baseline 2000 levels on a given highway segment, the model's travel demand elasticity features will modify the baseline VMT growth projections from HPMS.

Q. Does the accuracy of the investment requirements projected by HERS depend on how accurately the travel forecasts in HPMS predict what future VMT growth will be?

A. Not exactly. The HERS model assumes the travel forecasts in HPMS accurately predict what future VMT growth *would* be if highway-user costs remained constant, rather than what future growth *will* be. This is a critical distinction.

The accuracy of the investment requirements depends on the accuracy of the travel forecasts in HPMS *as modified by the travel demand elasticity features in HERS*. At current funding levels, HERS predicts that highway-user costs will increase over time, so VMT will grow more slowly than the HPMS baseline forecasts. This concept is discussed in more detail in Appendix A.

The HERS model utilizes VMT growth projections to predict future conditions and performance of individual highway segments and to calculate future investment requirements. If the HPMS VMT forecasts *as modified by the HERS travel demand elasticity features* are overstated, the investment requirement projections may be too high. If the travel growth is underestimated, the investment requirement projections may be too low.

The effective VMT growth rates predicted by the HERS model could be off target if either the HPMS forecasts don't precisely represent the travel that will occur if a constant level of service is maintained, or if the travel demand elasticity procedures in HERS don't accurately predict the response that highway-users will have to changes in costs. The latter effect is addressed in the next section by varying the values of the elasticity parameters used in the model. This section explores the impacts of the former case by modifying the estimates of future travel found in the HPMS sample data.

As indicated in Chapter 9, the State-supplied VMT growth projections in HPMS for 2000 to 2020 average 2.08 percent per year, well below the 2.99 average annual VMT growth rate observed from 1980 to 2000.

The HERS model assumes that the 2.08 percent composite VMT growth projection in HPMS represents the growth that will occur at a constant level of service. If this forecast understates future growth, the investment requirements will be higher than predicted.

Exhibit 9-6 shows the impact of different levels of future investment on the average annual VMT growth rate, if one assumes that the baseline travel growth forecasts in HPMS represent a constant level of service. Exhibit 10-1 shows the impact on investment requirements of assuming that the VMT growth that would occur at a constant level of service is different from what is indicated in the HPMS forecasts. The first line assumes a growth rate of 2.99 percent annually (matching the actual average annual growth rate over the last 20 years), rather than the 2.08 percent rate derived from the HPMS forecasts. This is achieved by factoring up the growth rates entered into the HERS model for each section by 43.8 percent. Modifying the travel growth projections in this fashion would increase the Cost to Maintain Highway and Bridges by 52.5 percent. Increased VMT would increase the rate of pavement deterioration, as well as increase the share of resources that HERS would recommend using for capacity expansion to over 50 percent of total spending. Both of these factors would tend to increase the investment required to maintain user costs at 2000 levels. The Cost to Improve Highways and Bridges would increase by 50.4 percent based on this change in assumptions. The increased travel would increase the number of pavement and capacity projects that HERS would find to be cost-beneficial.

The second line in Exhibit 10-1 shows what the projected investment requirements would be if the average VMT growth rate at a constant level of service were 1.17 percent rather than 2.08 percent. This value represents the effect of doubling the decline in the average annual VMT growth rate (relative to the historic values) that is implicit in the HPMS forecasts (i.e., the average annual growth rate over 20 years would drop from 1.82 percent (2.99 to 1.17) rather than by 0.91 percent (2.99 to 2.08)). The impact on the Cost to Maintain Highways and Bridges would be a decrease of 30.6 percent, and the impact on the Cost to Improve Highways and Bridges would be a decrease of 29.2 percent.

Exhibit 10-1

Impact of Alternate VMT Growth Assumptions on Investment Requirements

	Cost to Maintain Highways & Bridges		Cost to Improve Highways & Bridges	
	($BILLIONS)	PERCENT CHANGE	($BILLIONS)	PERCENT CHANGE
Chapter 7 Baseline	$75.9		$106.9	
Overall VMT Growth Rates				
Increased from 2.08% to 2.99%	$115.8	52.5%	$160.8	50.4%
Decreased from 2.08% to 1.17%	$52.7	-30.6%	$75.7	-29.2%

Source: Highway Economic Requirements System (HERS).

Alternative Model Parameters

The HERS model uses several key input parameters whose values may be subject to considerable uncertainty or debate. To assess the importance of such uncertainty, the estimates of future investment requirements were recomputed using different values for some of these parameters, including short run and long run elasticity; the value of ordinary travel time; the value of reductions in incident delay; the value of a statistical life; improvement costs; and truck share growth. Exhibit 10-2 shows the impacts of the alternative parameter values on the Cost to Improve Highways and Bridges.

Elasticity Values

The travel demand elasticity values used in this report were -0.6 for short term elasticity with an additional -0.4 (total -1.0) for the long term share. In the 1999 C&P report, values of -1.0 and -0.6 (total -1.6) were used. The changes in the elasticity procedures are explained in Appendix A.

Under the highway Maximum Economic Investment scenario, highway user costs are projected to decline. At this level of investment, the elasticity procedures in HERS tend to induce travel growth. Therefore, raising the elasticity values back to the levels used in the 1999 C&P report would increase the amount of induced travel and thus increase the investment requirements slightly.

Exhibit 10-2

Impact of Alternate Model Features and Parameters on Investment Requirements Cost to Improve Highways & Bridges

	($BILLIONS)	PERCENT CHANGE
Chapter 7 Baseline	$106.9	
Elasticity Values		
Use 1999 C&P Values	$107.6	0.7%
Value of Ordinary Travel Time		
Increase 100 percent	$119.3	11.7%
Reduce 50 percent	$98.2	-8.1%
Value of Incident Delay Reduction		
3 times value of ordinary travel time	$108.7	1.7%
Equal to value of ordinary travel time	$105.4	-1.4%
Value of a Statistical Life		
Increase 100 percent	$107.3	0.4%
Reduce 50 percent	$106.7	-0.2%
Improvement Costs		
Increase 25 percent	$124.1	16.1%
Truck Shares		
Increasing by 0.9 percent annually	$107.3	0.4%

Source: Highway Economic Requirements System (HERS).

Value of Ordinary Travel Time

The value of time in HERS was developed using a standard methodology adopted by the U. S. Department of Transportation (USDOT). This methodology provides consistency among different analyses performed within the Department. However, there is a great deal of debate about the appropriate way to value time, and no single methodology has been uniformly accepted by the academic community, or within the Federal Government.

Doubling the value of ordinary travel time in HERS would increase the Cost to Improve Highways and Bridges by 11.7 percent. Increasing the value of time causes HERS to consider more widening projects (which reduce travel time costs) to be cost-beneficial. The proportion of capacity projects implemented as a percentage of total investment would increase, to over 49 percent of total improvement costs. Reducing the value of time by 50 percent would have the opposite effect, resulting in an 8.1 percent reduction in the Cost to Improve Highways and Bridges.

Value of Incident Delay Reduction

As noted in Appendix A and elsewhere in this report, the HERS model has recently been modified to calculate the delay associated with traffic incidents (such as crashes), in addition to recurring congestion delay and signal delay. Research has indicated that such unpredictable delay is even more "costly" to highway users (on a per-hour basis) than is the predictable, routine delay typically associated with peak traffic volumes. The HERS model accounts for this by allowing for a user-specified parameter for the "reliability premium" associated with reductions in incident delay, which is expressed as a multiple of the value of ordinary travel time.

The estimates of investment requirements in Chapters 7 and 8 used a baseline value of 2.0 times the value of ordinary travel time for the reliability premium, which was chosen on the basis of available research. Exhibit 10-2 shows the impacts of setting this premium at a) 3.0 times the ordinary travel time value and b) equal to that value.

Changing the reliability premium associated with incident delay reductions has an effect similar to changing the value of ordinary travel time, though smaller in magnitude. Increasing the reliability premium to 3.0 makes incident delay-reducing improvements relatively more valuable, thereby raising investment requirements by 1.7 percent at the Cost to Improve level. Reducing the premium to 1.0 results in a corresponding reduction of 1.4 percent in the investment estimate.

Value of a Statistical Life

HERS uses $3.0 million for the value of a statistical life, which is the USDOT's standard value for use in benefit-cost analyses. As in the case with the value of time, there is a great deal of debate about the appropriate value, and no single dollar figure has been uniformly accepted by the academic community or within the Federal Government.

Doubling the value would increase the Cost to Improve Highways and Bridges by 0.4 percent. HERS would find a few more projects to implement on the basis of their increased safety benefits if the value of life were increased. Reducing the value of a statistical life by 50 percent would reduce the Cost to Improve Highways and Bridges by 0.2 percent. A few marginal projects that were justified based on potential reductions in crash rates would not be implemented if the value of life used in the analysis were reduced.

Changing the value of a statistical life in HERS does not have a significant impact on the estimates of annual investment requirements. The model is not currently equipped to consider all the safety benefits of highway improvements or safety-oriented projects. Improving the HERS model's capabilities in this area will be the target of future research.

Improvement Costs

The unit improvement costs used in HERS to calculate total investment costs may themselves be subject to uncertainty. For example, currently unforeseen circumstances may cause highway construction costs to increase faster than the general rate of inflation in the future. It is therefore prudent to consider the impact of higher-than-expected capital improvement costs, in order to ensure that non-cost-beneficial projects are not mistakenly included in the investment requirements estimated by HERS.

Exhibit 10-2 shows the impact of inflating all the improvement costs used by HERS by 25 percent on the Cost to Improve Highways and Bridges. The increase in investment requirements due to higher unit values for the improvement costs is partially offset by the elimination of some projects that would no longer be considered cost-beneficial by HERS. The net result is an increase of 16.1 percent in the estimated investment requirements.

Truck VMT Shares

The HPMS sample data used in HERS include values for the percentage of single-unit and combination trucks in the current vehicle mix on each segment. Forecasts of future traffic, however, are not broken down by vehicle class, meaning that the data effectively assume no changes in truck shares. Many national forecasts of future VMT, however, indicate that truck travel is expected to grow faster than passenger auto travel.

The HERS model includes a parameter for adjusting the truck share on each functional class over time according to an exogenously specified value, thus allowing the model to simulate changes in the vehicle mix over the 20-year forecast period. The factor used to generate the changes in HERS was drawn from a recent projection of future VMT for different vehicle classes made for FHWA (referenced in Chapter 9). The data in that study suggest that the average VMT share of trucks is expected to increase from 7.7 percent in 2000 to 9.2 percent in 2020. Exhibit 10-2 indicates that accounting for such a change within the HERS estimation procedures would increase the Cost to Improve Highways by 0.4 percent. HERS finds a small number of additional projects to be cost beneficial when the larger truck shares are accounted for.

Impacts of Alternative Parameters on the Cost to Maintain Highways and Bridges

The impacts of alternative model parameters and procedures on the estimated investment requirements are more ambiguous for the Cost to Maintain Highways and Bridges (see Exhibit 10-3) than for the Cost to Improve results reported above. This is due to the way in which the Cost to Maintain Highways and Bridges is defined in this report. (See Chapter 7.) The HERS-modeled portion of this cost was based on the Maintain User Cost scenario, in which investment is sufficient to allow average highway user costs for 2020 as calculated by HERS to match the initial levels in 2000. The initial calculation of user costs, however, is directly affected by many of the parameters shown in the exhibit, including the values of time, incident delay, statistical life, and truck shares. As a result, the average user cost that is maintained will be different for alternative values of these parameters, so the reader should exercise caution in interpreting Exhibit 10-3. The impacts of alternative values on the Cost to Improve, however, are based on implementing all cost-beneficial projects and are thus not subject to this same caveat.

In the case of the ordinary travel time, reliability premium, and value of statistical life parameters, increasing the value of these parameters also increases the initial calculated

Exhibit 10-3

Impact of Alternate Model Features and Parameters on Investment Requirements
Cost to Maintain Highways & Bridges

	($BILLIONS)	PERCENT CHANGE
Chapter 7 Baseline	$75.9	
Elasticity Values		
Use 1999 C&P Values	$73.5	-3.2%
Value of Ordinary Travel Time		
Increase 100 percent	$72.8	-4.1%
Reduce 50 percent	$78.4	3.3%
Value of Incident Delay Reduction		
3 times value of ordinary travel time	$74.5	-2.0%
Equal to value of ordinary travel time	$76.5	0.8%
Value of a Statistical Life		
Increase 100 percent	$75.7	-0.4%
Reduce 50 percent	$76.0	0.0%
Improvement Costs		
Increase 25 percent	$91.8	20.9%
Truck Shares		
Increasing by 0.9 percent annually	$83.2	9.6%

Source: Highway Economic Requirements System (HERS) value of user costs. Maintaining this higher level in the future may thus artificially require a smaller amount of future capital investment, due solely to the change in the baseline values. The effect is to lower the estimated Cost to Maintain when these parameters are increased, while the opposite is true for reduced values of the same parameters.

Increasing the share of trucks over time has the opposite effect on the Maintain User Costs scenario in HERS. Since trucks have higher travel time and vehicle operating costs than do passenger vehicles, an increasing truck share will cause average user costs to rise as well. More investment is then required to maintain user costs at the initial level. For the elasticity parameters, a larger value will cause more travel to be suppressed in the future, thereby reducing investment requirements.

Increasing the unit improvement costs in HERS by 25 percent causes a slightly less-than-proportional increase in the estimated Cost to Maintain Highways and Bridges. The reason for this is that the Cost to Maintain includes bridge preservation investments modeled in the National Bridge Investment Analysis System (NBIAS), which are not affected by changes in the HERS parameters.

Q. Are there any sensitivity analysis results available from the NBIAS model?

A. Yes. NBIAS applies a swell factor to maintenance, repair, and rehabilitation (MR&R) needs to account for the way in which such projects are implemented in practice. When State and local governments repair or rehabilitate deficient components of bridges, they typically try to raise the standards of other components that might not yet be deficient. In other words, MR&R actions cannot be viewed in isolation, and a swell factor is applied for these related improvements. This logic was also applied to the NBIAS results in the 1999 C&P report.

For this report, a swell factor of 1.25 was assumed. Assuming an alternate value of 1.12 reduces the Cost to Improve Highways and Bridges by 10.5 percent and reduces the Cost to Maintain Highways and Bridges by 5.7 percent. A 1.0 swell factor reduces the Cost to Improve Highways and Bridges by 20.5 percent and reduces the Cost to Maintain Highways and Bridges by 15.8 percent.

NBIAS is currently being improved so that individual bridge analysis can be done for MR&R needs. This will eliminate the need for a swell factor in future reports.

Transit Sensitivity Analyses

This section examines the sensitivity of projected transit investment requirements by the Transit Economic Requirements Model (TERM) to variations in the values of the following exogenously determined model inputs:

- Passenger miles traveled (PMT).
- Capital costs.
- Value of time.

These alternative projections illustrate how transit requirements vary according to different assumptions of these input values.

Sensitivity to Changes in PMT

TERM relies heavily on forecasts of PMTs in large urbanized areas. In fact, these forecasts are the primary driver behind TERM's estimates of the extent to which the Nation's transit system will need to be expanded in order to maintain performance. Transit PMT forecasts are generally made by metropolitan planning organizations (MPOs) in conjunction with projections of vehicle miles traveled (VMT) as a part of the regional transportation planning process. They implicitly incorporate assumptions about the relative growth of travel by transit and automobile. The average annual growth rate in PMT of 1.6 percent used in this report is a weighted average of the most recent, primarily 2001, MPO forecasts available from 33 of the Nation's largest metropolitan areas.

Future transit investment requirements have been estimated by TERM on the basis of three alternative projected PMT scenarios to examine the effect of variations in PMT growth on projected investment needs. *[See Exhibit 10-4].* These scenarios are:

1) PMT growth is 50 percent greater than the forecast levels.
2) PMT growth is 50 percent less than the forecast levels.
3) There is no growth in transit PMT.

Exhibit 10-4

Impact of Alternative PMT Growth Rates on Transit Investment Requirements*

	Annual Cost to Maintain Conditions & Performance		Annual Cost to Improve Conditions & Performance	
ANNUAL PMT GROWTH RATE	**(BILLIONS OF 2000 DOLLARS)**	**PERCENT CHANGE**	**(BILLIONS OF 2000 DOLLARS)**	**PERCENT CHANGE**
Baseline (1.60%)	$14.80	-	$20.6	-
Increased 50% (to 2.40%)	$17.40	17.6%	$23.2	12.6%
Decreased 50% (to 0.80%)	$12.10	-18.2%	$17.9	-13.1%
Decreased 100% (to 0%)	$9.20	-37.8%	$15.0	-27.2%

*Investment requirements for rural and special service vehicles are included in the totals, but are not subject to the sensitivity analysis. They account for 5 percent or less of the total.

Source: Transit Economic Requirements Model and FTA staff estimates.

Varying the assumed rate of growth in PMT significantly affects estimated transit investment requirements. This effect is more pronounced under the Maintain Conditions and Performance scenario as PMT growth rates influence asset expansion costs, which comprise a larger portion of total estimated Maintain Conditions and Performance needs. A 50 percent increase/decrease in growth will increase/decrease the cost to Maintain Conditions by 18 to 19 percent and the cost to Improve Conditions and Performance by 13 to14 percent. Investment requirements decrease by over 25 percent if PMT remains constant, although this is not a likely scenario.

Sensitivity to a 25 Percent Increase in Capital Costs

Capital costs used in TERM are based on actual prices paid by agencies for asset purchases as reported to FTA in several surveys. Asset prices have been converted to 2000 dollars as necessary. 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 projected transit investment requirements.

As shown in Exhibit 10-5, a 25 percent increase in capital costs increases both the costs to Maintain Conditions and Performance and to Improve Conditions and Performance by close to the full 25 percent increase. These results indicate that total benefits continue to exceed total costs for most investments, even with a 25 percent increase in costs.

Exhibit 10-5

Impact of a 25 Percent Increase in Capital Cost on Transit Investment Requirements*

	Annual Cost to Maintain Conditions & Performance		Annual Cost to Improve Conditions & Performance	
ANNUAL PMT GROWTH RATE	(BILLIONS OF 2000 DOLLARS)	PERCENT CHANGE	(BILLIONS OF 2000 DOLLARS)	PERCENT CHANGE
Baseline (1.60%)	$14.8	---	$20.6	---
Increase Costs 25%	$18.2	23.0%	$25.3	22.9%

*Investment requirements for rural and special service vehicles are included in the totals, but are not subject to the sensitivity analysis. They account for 5 percent or less of the total.

Source: Transit Economic Requirements Model and FTA staff estimates.

Impact of Change in the Value of Time

The value of time is a key input to TERM's benefit-cost test for all proposed capital investments. Specifically, the value of time is used to determine the total benefits accruing to transit users from transit investments that reduce passenger travel time. Hence, increases in the value of time should further multiply the estimated user benefits of such projects.

Exhibit 10-6 shows the effect of varying the value of time, assumed to be $9.85 per hour in the baseline projections. Overall, variations in the value of time have a very limited effect on investment needs. While increases in the value of time increase the benefits of transit projects that reduce travel times, it decreases the benefits of investment in transit modes that are slower than alternative non-transit modes of travel, such as the automobile. Therefore, an increase in the value of time reduces projected investment in agencies/modes with relatively slower transit service (as travel shifts from transit to automobiles) and increases projected investment requirements in agencies/modes with relatively faster transit services (as travel shifts from automobiles to transit). The opposite occurs in response to a decrease in the value of time.

Exhibit 10-6

Impact of Change in the Value of Time* on Transit Investment Requirements

	Annual Cost to Maintain Conditions & Performance		Annual Cost to Improve Conditions & Performance	
ANNUAL PMT GROWTH RATE	**(BILLIONS OF 2000 DOLLARS)**	**PERCENT CHANGE**	**(BILLIONS OF 2000 DOLLARS)**	**PERCENT CHANGE**
Baseline	$ 14.4	---	$ 19.5	---
Increase 100%	$ 14.6	0.0	$ 19.7	0.0
Decrease by 50%	$ 14.4	-0.1%	$ 19.5	-0.3%

* Investment requirements for rural and special service vehicles are included in the totals, but are not subject to the sensitivity analysis. They account for 5 percent or less of the total.

Source: Transit Economic Requirements Model.