CHAPTER 10: Impacts of Investment

Impacts of Investment – Highways

The analyses presented in this section use a common set of assumptions to derive relationships between alternative levels of future highway capital investment and various measures of future highway and bridge conditions and performance. A subsequent section in this chapter provides comparable information for different types and levels of potential future transit investments. The analyses described in this chapter make no explicit assumptions regarding how future investment in highways could be funded.

KEY TAKEAWAYS

- HERS results indicate it is cost-beneficial to reduce the percentage of travel on pavements with poor ride quality, but not necessarily to reduce average pavement roughness. For Interstate highways, average IRI would get slightly worse even at the Improve Conditions and Performance scenario level.
- Unlike for bridges overall, NBIAS results suggest that if spending is sustained at recent levels for bridges on Federal-aid highways, NHS bridges and Interstate bridges would be insufficient to keep the deck area-weighted share of bridges in poor condition from rising over time.

This section examines the types of investments used within the scopes of the Highway Economic Requirements System (HERS) and the National Bridge Investment Analysis System (NBIAS) and provides more context for the capital investment scenarios for highways presented in Chapter 7. The accuracy of projections for highway investments in this chapter depends on the validity of the technical assumptions underlying the analysis, some of which are explored in the sensitivity analysis in Chapter 9.

HERS, NBIAS, and Nonmodeled Inputs to the Improve Conditions and Performance Scenario

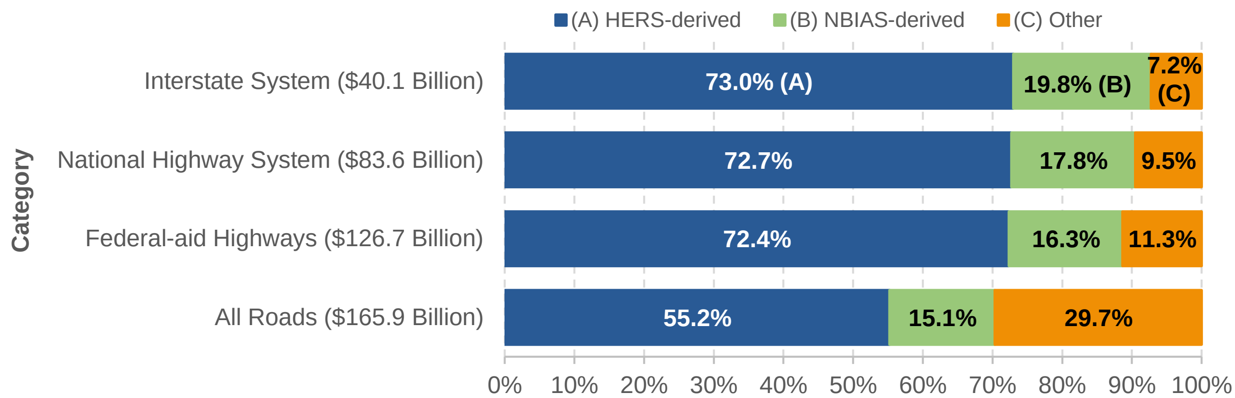
Exhibit 10-1 illustrates the derivation of the Improve Conditions and Performance scenario presented in Chapter 7. Of the $165.9 billion average annual investment level for all public roads under this scenario, 15.1 percent was derived from NBIAS (corresponding to the $25.1 billion identified as "System Rehabilitation – Bridge" in the "All Public Roads" row) and 55.2 percent was derived from HERS (corresponding to the $60.2 billion and $31.5 billion identified as "System Rehabilitation – Highways" and "System Expansion," respectively, in the "Federal-aid Highways" row). The remaining 29.7 percent was nonmodeled; this corresponds to the $23.5 billion identified as "System Enhancement" in the "All Public Roads" row plus the difference between the amounts shown in the "All Public Roads" and the "Federal-aid Highway" rows for "System Rehabilitation – Highways" ($19.4 billion, computed as $79.6 billion minus $60.2 billion) and "System Expansion" ($6.3 billion, computed as $37.8 billion minus $31.5 billion). Each of the nonmodeled input values was computed using scaling procedures so that its share of the total scenario investment level would match its share of recent spending from 2012 through 2016.

Exhibit 10-1 also identifies the average annual investment levels resulting from applying the Improve Conditions and Performance scenario criteria to various system subsets including the Interstate Highway System ($40.1 billion), the National Highway System (NHS) ($83.6 billion, including the amount directed to Interstate highways), and Federal-aid Highways ($126.7 billion, including the amount directed to the NHS). The modeled share of investment on these systems is higher than for all public roads because HERS and NBIAS fully cover system rehabilitation and system expansion investments on these types of highways, and only system enhancement investment is outside the scope of the two models.

The average annual investment level for the Federal-aid highways is 72.4 percent HERS-derived, 16.3 percent NBIAS-derived, and 11.3 percent nonmodeled. The average annual investment level for the National Highway System is 72.7 percent HERS-derived, 17.8 percent NBIAS-derived, and

9.5 percent nonmodeled. The share of spending by source of estimate for the Interstate System is similar, with 73.0 percent HERS-derived, 19.8 percent NBIAS-derived, and 7.2 percent nonmodeled.

Exhibit 10-1 ■ Improve Conditions and Performance Scenario, 2017 Through 2036: Distribution by System, by Source of Estimate, and by Capital Improvement Type



System Component	System Rehabilitation			System Expansion[1]	System Enhancement	Total	Percent of Total
	Highway[1]	Bridge[2]	Total				
Average Annual Investment in Billions of 2016 Dollars							
Interstate Highway System	$16.8	$7.9	$24.8	$12.4	$2.9	$40.1	24.1%
National Highway System	$37.1	$14.9	$51.9	$23.7	$8.0	$83.6	50.4%
Federal-aid Highways	$60.2	$20.7	$80.8	$31.5	$14.3	$126.7	76.3%
All Roads	$79.6	$25.1	$104.7	$37.8	$23.5	$165.9	100.0%

Note: NBIAS is National Bridge Investment Analysis System; HERS is Highway Economic Requirements System.

[1] The "HERS-derived" share includes most outlays (All Roads are not included in the HERS-derived share) classified as "System Rehabilitation: Highway" and "System Expansion" except for the portions spent off of Federal-aid Highways, which are classified as "Other." The "Other" category also includes all outlays classified as "System Enhancement."

[2] The "NBIAS-derived" share includes all outlays classified as "System Rehabilitation: Bridge."

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

How were the investment levels presented in Exhibits 10-2 to 10-18 selected?

The particular investment levels shown in each exhibit were selected from the results of a much larger number of model simulations. All are meant to be illustrative; some were chosen to align with the scenarios presented in Chapter 7, but others were simply chosen to show a relatively even distribution of data points for the charts. There is no special significance to the lowest investment level shown in each table.

Most of the HERS and NBIAS analyses presented in this chapter assume a fixed amount of spending in constant dollars in each of the 20 years of the analysis period. However, the highest levels shown (the one or more shown above the bold horizontal line in the tables) are based on model runs constrained by a benefit-cost ratio.

Impacts of Federal-aid Highway Investments Modeled by HERS

Exhibit 10-2 introduces the seven investment levels presented in the next several exhibits to illuminate the relationship between the levels of investment modeled in HERS and the future conditions and performance of Federal-aid highways. The "Improve C&P" reference in the top row of *Exhibit 10-2* signifies that this level of investment feeds into the Improve Conditions and Performance scenario in Chapter 7, which is defined by attaining a minimum BCR of 1.0 in each year over the 20-year analysis period. The remaining six runs are funding-constrained, for which HERS ranks potential projects in order of BCR and implements them until the funding constraint is reached.

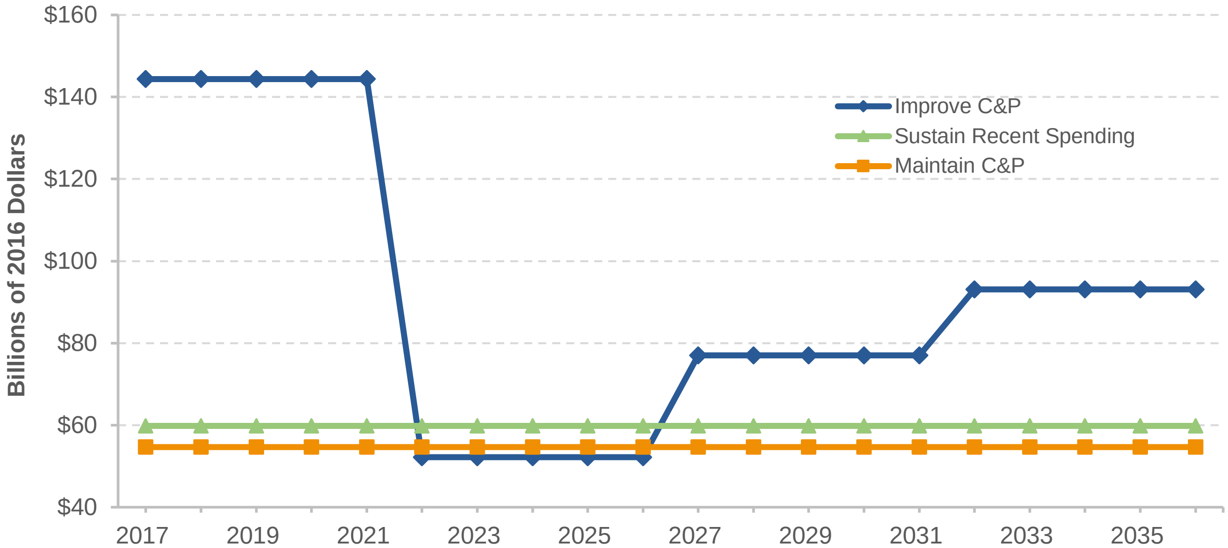
One funding level shown in *Exhibit 10-2* represents the spending level designed to match a specific level of performance in 2036; a spending level of $54.7 billion is projected to be adequate to allow average pavement roughness as measured by the International Roughness Index (IRI) in 2036 to match the level in 2016 (see discussion of IRI in Chapter 6) and for average delay to be at least as low in 2036 as it was in 2016. The Maintain C&P reference in *Exhibit 10-2* (in the "Link to Chapter 7 Scenario" column) signifies that this level of investment feeds into the Maintain Conditions and Performance scenario presented in Chapter 7. The Recent Spending reference indicates that this level of spending ($59.8 billion) supplies the Sustain Recent Spending scenario presented in Chapter 7. This represents the average annual level of constant-dollar investment from 2012 to 2016 that was directed toward the types of improvements modeled in HERS. The remaining four of the seven funding levels shown in *Exhibit 10-2* were selected to fill gaps between the three data points linked to specific scenarios, and to extend the lower end of the range of investment levels analyzed.

The portion of each investment level that HERS directs to system rehabilitation vs. system expansion is important, as these types of investments have varying degrees of influence on different performance measures. Investment in system rehabilitation (ranging from $26.8 billion to $60.2 billion across reported investment levels) tends to have a stronger influence on physical condition measures such as pavement ride quality. Investment in system expansion (ranging from $15.2 billion to $31.5 billion across reported investment levels) has a more pronounced impact on operational performance measures such as delay.

Investment Levels and BCRs by Funding Period

Exhibit 10-2 illustrates how the seven future funding levels for Federal-aid highways that were selected for further analysis in this section would translate into cumulative spending in 5-year intervals (corresponding to 5-year analysis periods used in HERS). Achieving a minimum BCR of 1.0 in all four funding periods would require a 20-year investment of $1.833 trillion for the "Improve C&P" scenario. Within that period, HERS would invest $722 billion in the first 5 years, $261 billion in the second 5 years, $385 billion in the third 5 years, and $465 billion in the fourth 5 years. This front-loaded pattern is driven by the existence of a backlog of cost-beneficial investment opportunities, as referenced in Chapter 7. The investment levels for the other six rows remain constant in each 5-year funding period based on how these analyses were defined.

Exhibit 10-2 ■ HERS Annual Investment Levels Analyzed for Federal-aid Highways, 2017–2036



Spending Modeled in HERS (Billions of 2016 Dollars)									Link to Chapter 7 Scenario
Average Annual Over 20 Years			Cumulative						
Total HERS Spending	System Rehabilitation Spending[1]	System Expansion Spending[1]	5-year 2017 through 2021	5-year 2022 through 2026	5-year 2027 through 2031	5-year 2032 through 2036	20-year 2017 through 2036		
$91.7	$60.2	$31.5	$721.8	$261.0	$385.0	$465.4	$1,833.2	Improve C&P	
$80.0	$52.1	$27.9	$400.0	$400.0	$400.0	$400.0	$1,600.0		
$70.0	$45.2	$24.8	$350.0	$350.0	$350.0	$350.0	$1,400.0		
$59.8	$38.6	$21.2	$299.1	$299.1	$299.1	$299.1	$1,196.5	Recent Spending	
$54.7	$35.2	$19.5	$273.3	$273.3	$273.3	$273.3	$1,093.3	Maintain C&P	
$48.0	$30.7	$17.3	$240.0	$240.0	$240.0	$240.0	$960.0		
$42.0	$26.8	$15.2	$210.0	$210.0	$210.0	$210.0	$840.0		

Note: HERS is Highway Economic Requirements System.

[1] HERS splits its available budget between system rehabilitation and system expansion based on the mix of spending it finds to be most cost-beneficial, which varies by funding level.

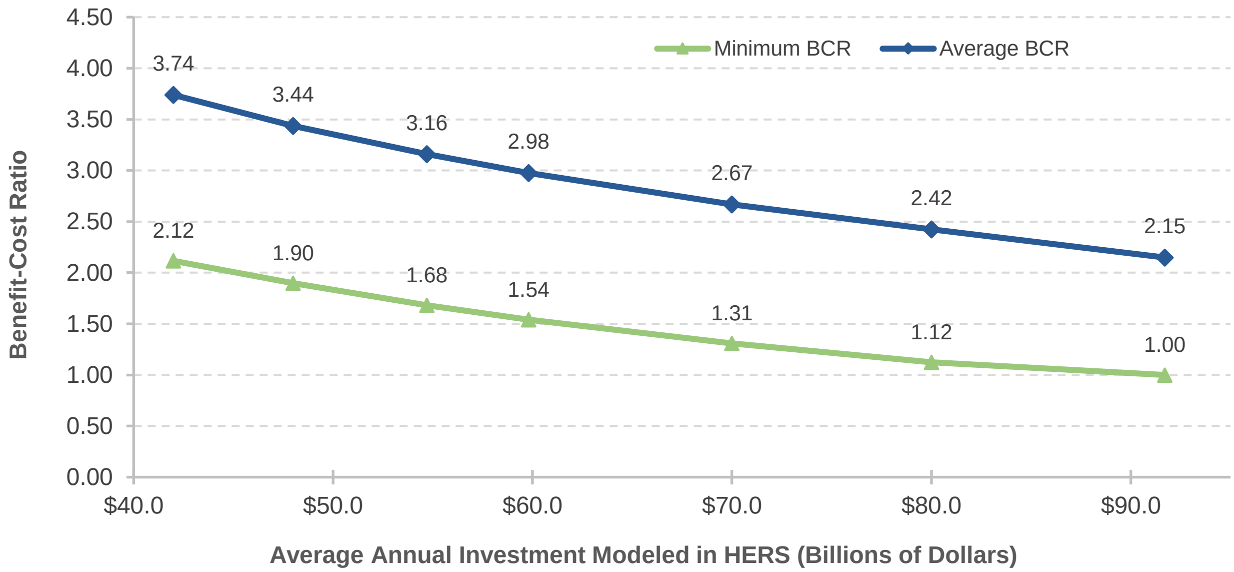
Source: Highway Economic Requirements System.

Exhibit 10-3 illustrates the marginal BCRs (i.e., the lowest BCR among the improvements selected within a funding period) associated with the seven future funding levels. *Exhibit 10-3* also provides the minimum BCRs across all funding periods (which represents the lowest marginal BCR) and the average BCRs across all funding periods (i.e., the total level of benefits of all improvements divided by the total cost of all improvements). The marginal BCRs for the top row are all 1.00, as this analysis allowed spending levels to vary by funding period specifically to result in this outcome. The marginal BCRs for the remaining rows vary by funding period, as these analyses held annual spending constant.

For the analyses assuming fixed levels of spending each year, the marginal BCR is highest in the first funding period and then declines over time, reflecting the tendency in HERS to implement the most worthwhile improvements first. However, by the fourth funding period, the marginal BCRs begin to creep back up slightly, so that the minimum BCR over the entire 20-year analysis period equals the marginal BCR in the third 5-year period. This pattern reflects the impacts of funding constraints: the relative scarcity of funding toward the end of the analysis period is inadequate to keep pace with newly emerging needs, limiting the range of needs that can be addressed.

Further evident in *Exhibit 10-3* is the inverse relationship between the minimum BCR and the level of investment. At any given level of average annual investment, the average BCR always exceeds the marginal BCR. For example, at the highest level of investment considered, an average annual investment level of $91.7 billion, the average BCR of 2.15 exceeds the minimum BCR of 1.00.

Exhibit 10-3 ■ Minimum and Average Benefit-Cost Ratios for Different Possible Funding Levels on Federal-aid Highways



HERS-modeled Investment on Federal-aid Highways Average Annual Investment (Billions of 2016 Dollars)	Benefit-cost Ratios[1]						Link to Chapter 7 Scenario
	Average BCR 20-year: 2017 through 2036	Marginal BCR[2]				Minimum BCR 20-Year: 2017 through 2036	
		5-year 2017 through 2021	5-year 2022 through 2026	5-year 2027 Through 2031	5-year 2032 through 2036		
$91.7	**2.15**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**Improve C&P**
$80.0	2.42	1.73	1.23	**1.12**	1.14	**1.12**	
$70.0	2.67	1.88	1.42	**1.31**	1.36	**1.31**	
$59.8	2.98	2.08	1.66	**1.54**	1.60	**1.54**	Recent Spending
$54.7	3.16	2.21	1.78	**1.68**	1.74	**1.68**	Maintain C&P
$48.0	3.44	2.38	1.95	**1.90**	1.97	**1.90**	
$42.0	3.74	2.59	2.17	**2.12**	2.18	**2.12**	

Note: HERS is Highway Economic Requirements System; BCR is benefit-cost ratio.

[1] As HERS ranks potential improvements by their estimated BCRs and assumes that the improvements with the highest BCRs will be implemented first (up until the point where the available budget specified is exhausted), the minimum and average BCRs will naturally tend to decline as the level of investment analyzed rises.

[2] The marginal BCR represents the lowest benefit-cost ratio for any project implemented during the period identified at the level of funding shown. The minimum BCRs, indicated by bold font, are the smallest of the marginal BCRs across the funding periods.

Source: Highway Economic Requirements System.

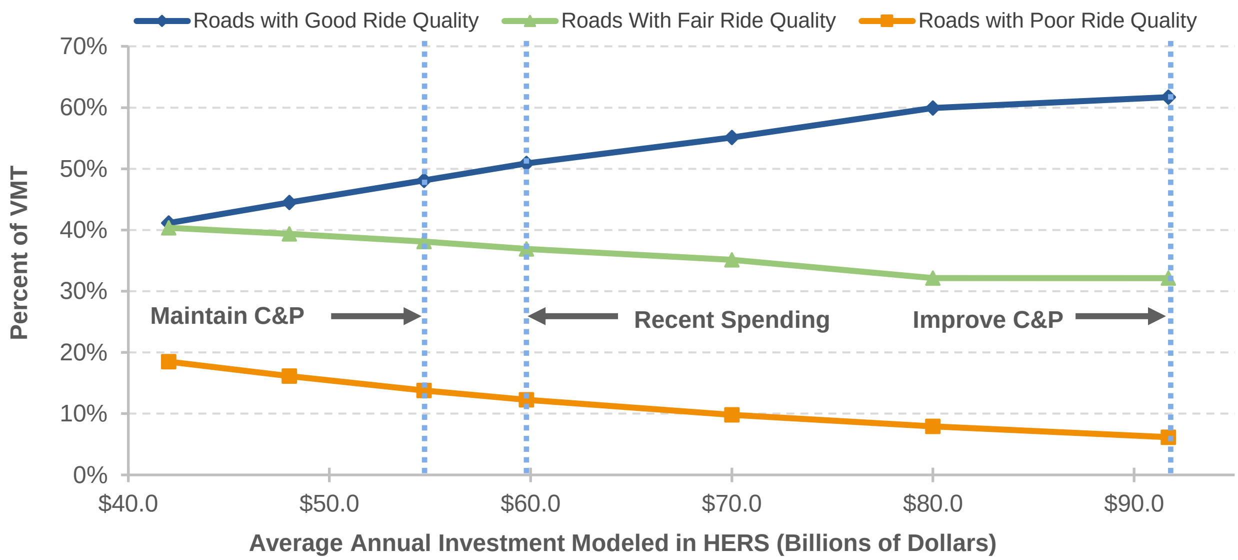
Impact of Future Investment on Ride Quality on Federal-aid Highways

For all investment levels above Maintain C&P presented in *Exhibit 10-4*, pavements on Federal-aid highways are projected to be smoother on average in 2036 than they were in 2016. At the highest level of annual investment analyzed ($91.7 billion, including $60.2 billion for system rehabilitation), VMT-weighted average IRI is projected to decrease by 16.4 percent. For the $54.7 billion average annual HERS investment level associated with the Maintain C&P scenario, pavements on Federal-aid highways are projected to be as smooth on average in 2036 as they were in 2016, whereas for the lower investment levels, Federal-aid highways are projected to have higher average IRI in 2036 than they did in 2016.

Exhibit 10-4 also shows the HERS projections for the percentage of travel occurring on pavements with ride quality that would be rated "good," "fair," and "poor" based on the IRI thresholds described in Chapter 6. Under all but the lowest annual level of investment analyzed ($42.0 billion, including $26.8 billion for system rehabilitation), the 2036 projection for the percentage of travel occurring on pavements with "poor" ride quality is lower than the 17.1 percent that occurred in 2016, as the model identifies significant user benefits that can be obtained by addressing pavement deficiencies. Among the rows depicting analyses with fixed annual investment levels, the improvement in the share of travel on pavements with "good" ride quality increases roughly linearly with spending, whereas the share of travel on roads with "fair" ride quality decreases roughly linearly with spending. The projections for the percentage of VMT with "good" ride quality for 2036 range from 61.7 percent at the highest level of average annual investment modeled to 41.1 percent at the lowest level of investment modeled.

As noted in Chapter 6, the IRI threshold of 170 used to identify fair ride quality was originally set to measure performance on the National Highway System (NHS) and may not be fully applicable to non-NHS routes, which tend to have lower travel volumes and speeds. This helps to explain why the percentage of VMT on roads with poor ride quality falls no lower than 6.2 percent, even when all cost-beneficial improvements are implemented. In some cases, the benefits of potential pavement improvements may not exceed their costs until the IRI has increased to a level well higher than the threshold of 170.

Exhibit 10-4 ■ Projected Impact of Alternative Investment Levels on 2036 Pavement Ride Quality Indicators for Federal-aid Highways



HERS-modeled Capital Investment Average Annual Spending (Billions of 2016 Dollars)		Projected 2036 Condition Measures on Federal-aid Highways[1,2]					
		Percent of VMT on Roads with Ride Quality of:			Average IRI (VMT-weighted)		
Total	System Rehabilitation[2]	Good (IRI<95)[3]	Fair (IRI 95 to 170)	Poor (IRI>170)[3]	Inches Per Mile	Change Relative to Base Year	Link to Chapter 7 Scenario
$91.7	$60.2	61.7%	32.1%	6.2%	97.1	-16.4%	Improve C&P
$80.0	$52.1	59.9%	32.2%	7.9%	101.1	-13.0%	
$70.0	$45.2	55.1%	35.1%	9.8%	106.5	-8.3%	
$59.8	$38.6	50.9%	36.9%	12.3%	112.5	-3.2%	Recent Spending
$54.7	$35.2	48.1%	38.1%	13.8%	116.2	**0.0%**	**Maintain C&P**
$48.0	$30.7	44.5%	39.4%	16.1%	121.3	4.4%	
$42.0	$26.8	41.1%	40.4%	18.5%	126.7	9.0%	
Base Year Values:		**48.9%**	**34.0%**	**17.1%**	**116.2**		

Note: IRI is International Roughness Index; VMT is vehicle miles traveled.

[1] The HERS model relies on information from the HPMS sample section database, which is limited to those portions of the road network that are generally eligible for Federal funding (i.e., "Federal-aid highways") and excludes roads classified as rural minor collectors, rural local, and urban local.

[2] The system rehabilitation component of HERS-modeled spending would likely have a greater impact on the performance indicators in this exhibit than would the system expansion component that is also reflected in the total.

[3] As discussed in Chapter 6, IRI values of 95 through 170 inches per mile are classified as "fair," lower IRI values are classified as "good," and higher IRI values are classified as "poor."

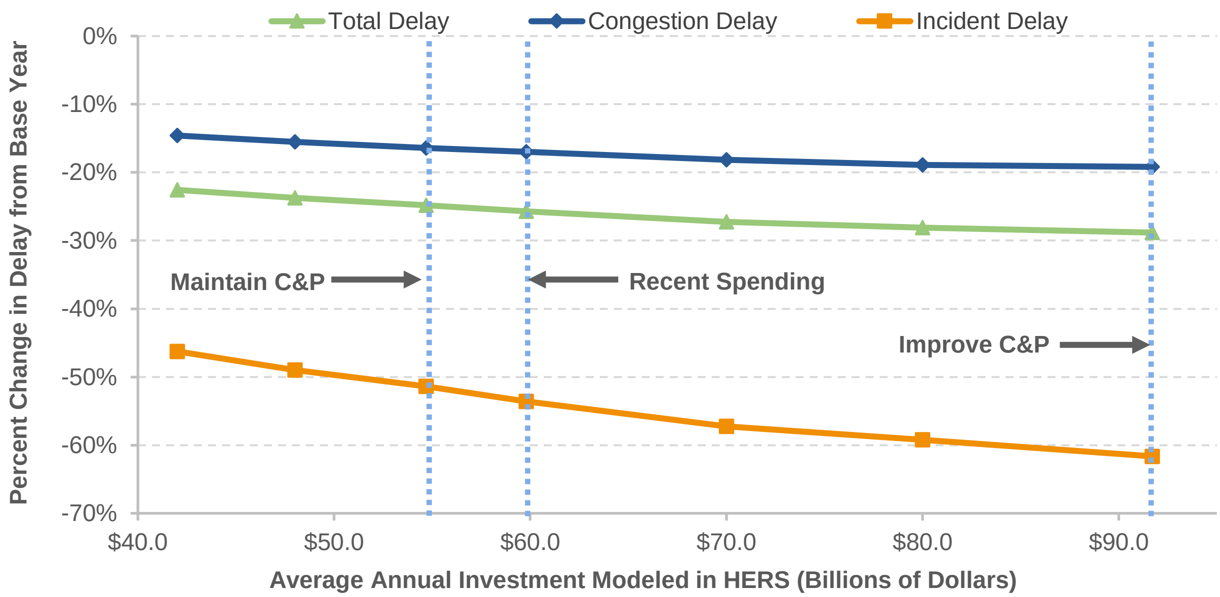
Source: Highway Economic Requirements System.

Impact of Future Investment on Travel Delay and Speed on Federal-aid Highways

Exhibit 10-5 shows the HERS projections for the impact of investment levels on average speed and travel delay. The exhibit splits out the portion of the investment that HERS allocates for system expansion, which tends to reduce congestion delay more than spending on system rehabilitation. The tabular portion of the exhibit shows that the levels of system expansion analyzed range from an average annual investment of $15.2 billion (which feeds into the Maintain Conditions and Performance scenario in Chapter 7) to an average annual investment of $31.5 billion (which feeds into the Improve Conditions and Performance scenario in Chapter 7). The graph is plotted based on total average annual investment modeled in HERS, including spending on both system rehabilitation and system expansion.

Across all investment levels presented in *Exhibit 10-5*, annual delay per vehicle in 2036 is lower than the 2016 level (52.4 hours), with reductions in delay ranging from 11.8 hours (52.4 hours minus 40.6 hours) in the lowest level of investment analyzed to 15.1 hours (52.4 hours minus 37.3 hours) in the highest. The projected increases in average vehicle speed are narrow, ranging from 45.8 miles per hour to 46.4 miles per hour, compared with the 2016 level of 43.5 miles per hour.

Exhibit 10-5 ■ Projected Impact of Alternative Investment Levels on 2036 Highway Travel Delay and Speed on Federal-aid Highways



HERS-modeled Capital Investment Average Annual Spending (Billions of 2016 Dollars)		Projected 2036 Performance Measures on Federal-aid Highways					Link to Chapter 7 Scenario
				Percent Change Relative to Base Year			
Total	System Expansion[1]	Average Speed in 2036 (mph)	Annual Hours of Delay per Vehicle[2]	Total Delay per VMT	Congestion Delay per VMT	Incident Delay per VMT	
$91.7	$31.5	46.4	37.3	-28.8%	-19.2%	-61.6%	Improve C&P
$80.0	$27.9	46.3	37.7	-28.1%	-18.9%	-59.2%	
$70.0	$24.8	46.3	38.1	-27.2%	-18.2%	-57.2%	
$59.8	$21.2	46.1	38.9	-25.7%	-17.0%	-53.6%	Recent Spending
$54.7	$19.5	46.0	39.4	-24.8%	-16.4%	-51.4%	Maintain C&P
$48.0	$17.3	45.9	40.0	-23.7%	-15.5%	-49.0%	
$42.0	$15.2	45.8	40.6	-22.6%	-14.6%	-46.2%	
Base Year Values:		**43.5**	**52.4**				

Note: HERS is Highway Economic Requirements System; VMT is vehicle miles traveled.

[1] The system expansion component of HERS-modeled spending would likely have a greater impact on the performance indicators in this exhibit than would the system rehabilitation component that is also reflected in the total.

[2] The values shown were computed by multiplying HERS estimates of average delay per VMT by 11,810, the average VMT per registered vehicle in 2016. HERS does not forecast changes in VMT per vehicle over time. The HERS delay figures include delay attributable to stop signs and signals as well as delay resulting from congestion and incidents.

Sources: Highway Economic Requirements System; Highway Statistics 2015, Table VM-1.

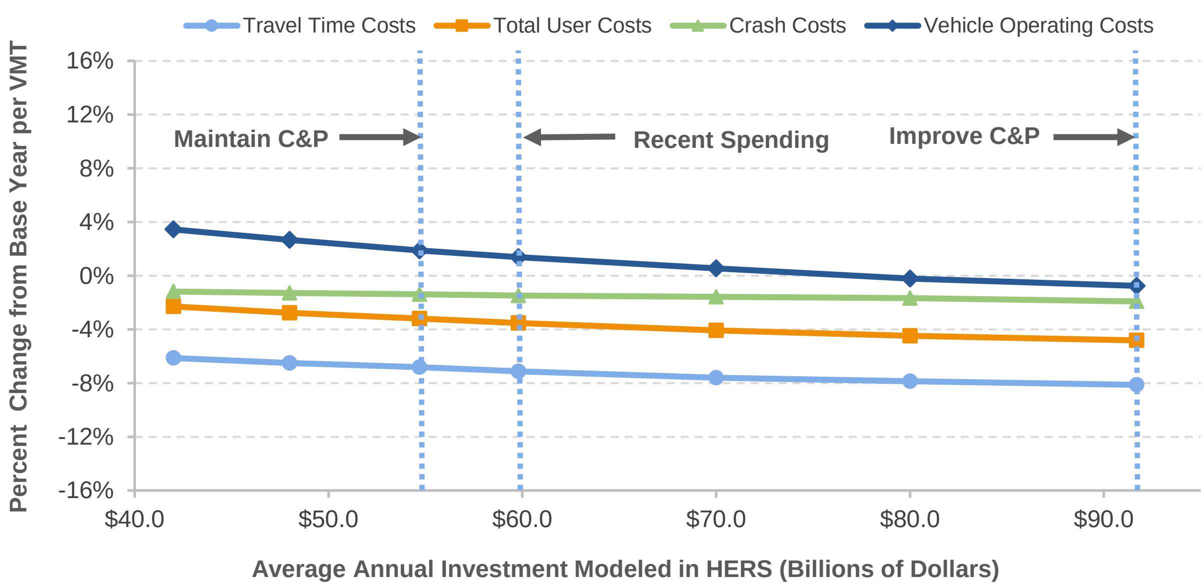
Some traffic basics are important to keep in mind when interpreting these results. In addition to congestion and incident delay, some delay inevitably results from traffic control devices, which interrupt traffic. For this reason, and because traffic congestion occurs only at certain places and times, *Exhibit 10-5* shows the variation in investment levels as having less impact on projections for total delay and average speed than on the projections for congestion and incident delay. In addition, although the impacts of additional investment on average speed are proportionally small, these impacts apply to a vast amount of travel; hence, the associated savings in user cost are not necessarily small relative to the cost of the investment.

Impact of Future Investment on Highway User Costs on Federal-aid Highways

In HERS, the benefits from highway improvements are measured as reductions in highway user costs, agency costs, and societal costs of vehicle emissions. In measuring the highway user costs, the model includes the costs of travel time, vehicle operation, and crashes.

Exhibit 10-6 shows the projected changes from 2016 in average user cost of travel on Federal-aid highways by cost component. For Federal-aid highways, HERS estimates that user costs—the costs of travel time, vehicle operation, and crashes—averaged $1.355 per mile traveled in 2016.

Exhibit 10-6 ■ Projected Impact of Future Investment Levels on 2036 User Costs on Federal-aid Highways



HERS-modeled Investment on Federal-aid Highways Average Annual Investment (Billions of 2016 Dollars)	Projected 2036 Performance Measures on Federal-aid Highways					Link to Chapter 7 Scenario
		Percent Change Relative to Base Year Average per VMT				
	Average Total User Costs ($/VMT)	Total User Costs	Travel Time Costs	Vehicle Operating Costs	Crash Costs	
$91.7	$1.289	-4.8%	-8.1%	-0.8%	-1.9%	Improve C&P
$80.0	$1.294	-4.5%	-7.9%	-0.2%	-1.7%	
$70.0	$1.300	-4.1%	-7.6%	0.6%	-1.6%	
$59.8	$1.307	-3.5%	-7.1%	1.4%	-1.5%	Recent Spending
$54.7	$1.311	-3.2%	-6.8%	1.9%	-1.4%	Maintain C&P
$48.0	$1.317	-2.8%	-6.5%	2.7%	-1.3%	
$42.0	$1.324	-2.3%	-6.1%	3.4%	-1.2%	
Base Year Values:	**$1.355**					

Note: HERS is Highway Economic Requirements System; VMT is vehicle miles traveled.
Source: Highway Economic Requirements System.

Average user cost per VMT is projected to decrease from the 2016 values by 2.3 percent at the lowest level of spending ($42.0 billion) to 4.8 percent at the highest level of spending ($91.7 billion, which feeds into the Improve Conditions and Performance scenario in Chapter 7). The cost of crashes is the user cost component with the lowest absolute sensitivity to the assumed level of highway investment. Crash costs in 2036 are projected to be between 1.2 percent and 1.9 percent lower than they were in 2016.

The levels of spending in each scenario are limited to the types of improvements that HERS evaluates, which are basically system rehabilitation and expansion. Because HPMS lacks detailed information on the current location and characteristics of safety-related features (e.g., guardrail, rumble strips, roundabouts, yellow change intervals at signals), safety-focused investments are not evaluated. Thus, the findings presented in *Exhibit 10-6* do not show how such investments affect highway safety.

Crash costs form the smallest of the three components of highway user costs. For 2016 travel on Federal-aid highways, HERS estimates the breakdown by cost component for each spending level. The average share of user costs across spending levels are as follows: crash cost, 15.0 percent; travel time cost, 52.8 percent; and vehicle operating cost, 32.2 percent. Research underway to update the vehicle operating cost equations in HERS (see Appendix A) could somewhat alter the split among these costs in future reports, but crash costs will likely remain a relatively small component. Although highway trips always consume traveler time and resources for vehicle operation, only a small fraction involve crashes. In addition, many crashes involve only damage to property with no injuries, particularly on urban highways.

The projections for travel time costs are less sensitive to the assumed level of investment than are the projections for vehicle operating costs. The projected 2016–2036 change in travel time cost per VMT ranges from a decrease of 8.1 percent at the highest level of assumed investment to a decrease of 6.1 percent at the lowest. These projections indicate that investing at the highest level rather than the lowest level would reduce the time cost of travel per VMT in 2036 by 2.0 percentage points, saving travelers hundreds of millions of hours per year in aggregate.

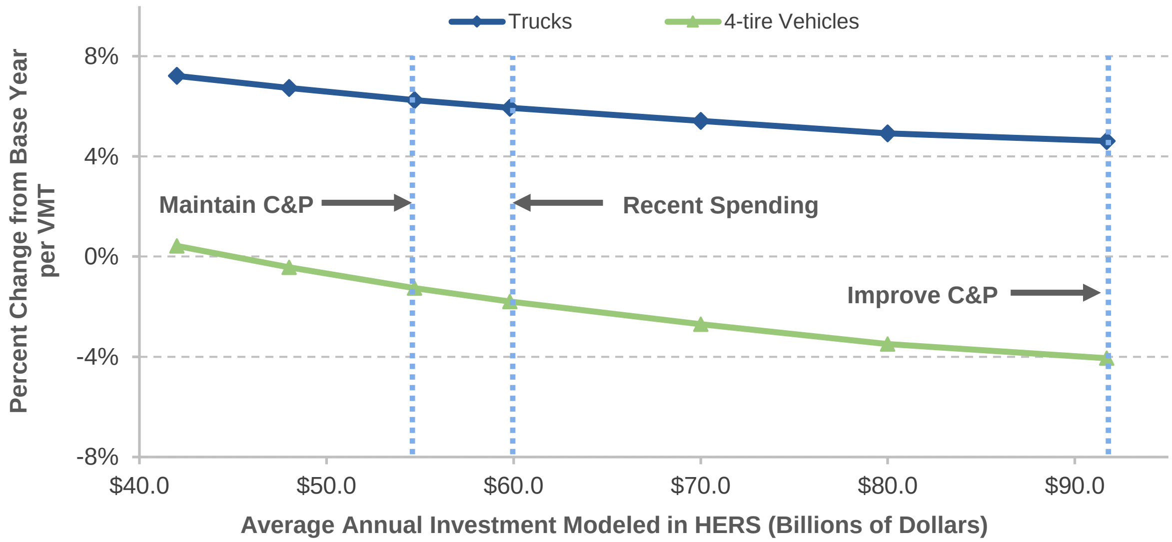
Impact on Vehicle Operating Costs

Exhibit 10-7 presents projections for vehicle operating costs per VMT, including separate values for four-tire vehicles (light-duty vehicles) and trucks (heavy-duty vehicles). Vehicle operating costs per mile are projected to decline by 1.8 percent at the Sustain Recent Spending investment level and by 4.1 percent at the Improve C&P investment level for four-tire vehicles from 2016 to 2036. Vehicle operating costs per mile for trucks are projected to increase by 5.9 percent and 4.6 percent for the same period, respectively.

The projected changes in vehicle operating costs per VMT are driven by projected increases in fuel prices and fuel efficiency across the analysis horizon. The assumed paths of fuel efficiency are based on projections from the U.S. Energy Information Administration's Annual Energy Outlook 2017.[31] The average price of gasoline is assumed to increase between 2016 and 2036 by 44.7 percent, whereas the average price of diesel fuel is assumed to increase by 71.7 percent for the same period. The projected changes in fuel prices are countered by the fuel cost savings that would result from the improvements in vehicle energy efficiency for the same period. These changes are represented in HERS as increases in average miles per gallon of 50.1 percent for light-duty vehicles, 40.0 percent for six-tire trucks, and 37.1 percent for other trucks. The net result is that the average vehicle operating costs for four-tire vehicles are projected to decline across all but the lowest funding level (at $42.0 billion), whereas these costs for trucks are projected to increase across all funding levels.

[31] https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf

Exhibit 10-7 ■ Projected Impact of Future Investment Levels on 2036 Vehicle Operating Costs on Federal-aid Highways



HERS-modeled Investment on Federal-aid Highways Average Annual Investment (Billions of 2016 Dollars)	Projected 2036 Performance Measures on Federal-aid Highways: Average Vehicle Operating Costs			Projected 2036 Performance Measures on Federal-aid Highways: Percent Change Relative to Base Year		Link to Chapter 7 Scenario
	All Vehicles ($/VMT)	4-tire Vehicles ($/VMT)	Trucks ($/VMT)	4-tire Vehicles	Trucks	
$91.7	$0.432	$0.360	$1.011	-4.1%	4.6%	Improve C&P
$80.0	$0.435	$0.362	$1.014	-3.5%	4.9%	
$70.0	$0.438	$0.365	$1.019	-2.7%	5.4%	
$59.8	$0.442	$0.368	$1.024	-1.8%	5.9%	Recent Spending
$54.7	$0.444	$0.370	$1.027	-1.3%	6.2%	Maintain C&P
$48.0	$0.447	$0.373	$1.031	-0.4%	6.7%	
$42.0	$0.451	$0.376	$1.036	0.4%	7.2%	
Base Year Values:	**$0.436**	**$0.375**	**$0.966**			

Note: VMT is vehicle miles traveled; HERS is Highway Economic Requirements System.

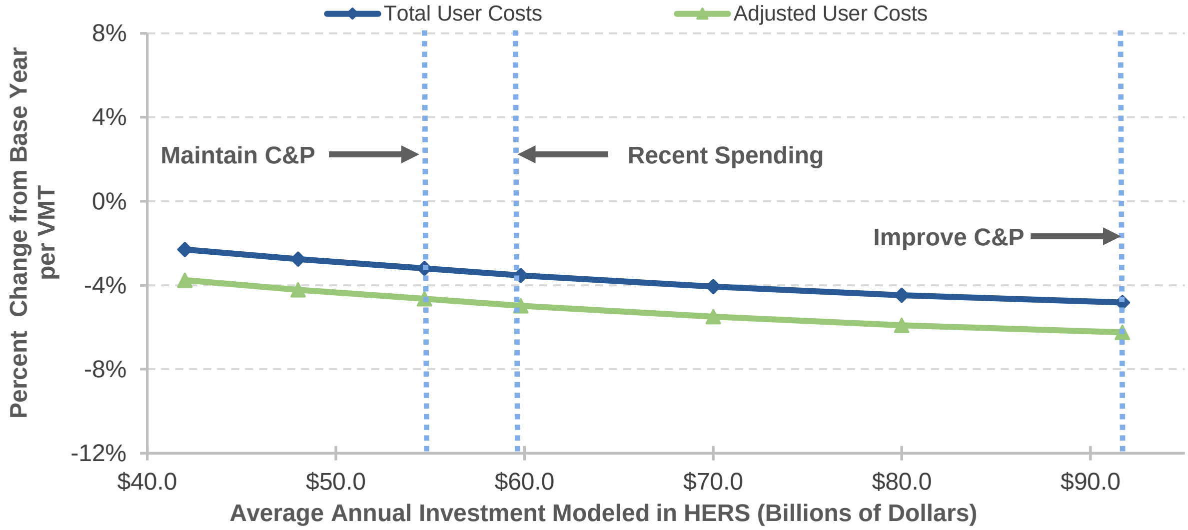
Source: Highway Economic Requirements System.

Impact of Future Investment on VMT

As discussed earlier, the travel demand elasticity features in HERS modify future VMT growth for each HPMS sample section based on changes to highway user costs. In addition, HERS is now programmed to assume that the baseline projections of future VMT already account for anticipated independent changes in user cost component values such as fuel prices and fuel efficiency.

In computing the impact of user cost changes on future VMT growth on an HPMS sample section, HERS compares projected highway user costs against assumed user costs that would have occurred had the physical conditions or operating performance on that highway section remained unchanged. This concept is illustrated in *Exhibit 10-8*. Based on the 2016 values assigned to various user cost components (e.g., value of travel time per hour, fuel prices, fuel efficiency, truck travel as a percentage of total travel), HERS computes baseline 2016 user costs at $1.355 per mile. If the 2036 values assigned to those same user cost components were applied in 2016, however, HERS would compute 2016 user costs to be $1.375 per mile. This "adjusted baseline" is the relevant point of comparison when examining the impact of user cost changes on VMT.

Exhibit 10-8 ■ Projected Impact of Future Investment Levels on 2036 User Costs and VMT on Federal-aid Highways



HERS-modeled Investment on Federal-aid Highways Average Annual Investment (Billions of 2016 Dollars)	Projected 2036 Indicators on Federal-aid Highways					Link to Chapter 7 Scenario
	Average Total User Costs[1]			Projected VMT[2]		
	($/VMT)	Percent Change vs. Actual 2016	Percent Change vs. Adjusted Baseline	Trillions of VMT	Annual Percent Change vs. 2016	
$91.7	$1.289	-4.82%	-6.24%	3.585	1.48%	Improve C&P
$80.0	$1.294	-4.47%	-5.90%	3.552	1.44%	
$70.0	$1.300	-4.07%	-5.50%	3.532	1.41%	
$59.8	$1.307	-3.54%	-4.98%	3.508	1.37%	Recent Spending
$54.7	$1.311	-3.20%	-4.64%	3.493	1.35%	Maintain C&P
$48.0	$1.317	-2.76%	-4.21%	3.472	1.32%	
$42.0	$1.324	-2.30%	-3.76%	3.453	1.29%	
Base Year Values:	**$1.355**			**2.670**	**1.20%**	
Adjusted Baseline:	**$1.375**					

Note: VMT is vehicle miles traveled; HERS is Highway Economic Requirements System.

[1] The computation of user costs includes several components (value of travel time per hour, fuel prices, fuel efficiency, truck travel as a percentage of total travel, etc.) that are assumed to change over time independently of future highway investment. The adjusted baseline applies the parameter values for 2036 to the data for 2016 so that changes in user costs attributable to future highway investment can be identified.

[2] The operation of the travel demand elasticity features in HERS causes future VMT growth to be influenced by future changes in average user costs per VMT. For this report, the model was set to assume that the baseline projections of future VMT already take into account anticipated independent future changes in user cost component values; hence, it is the changes vs. the adjusted baseline user costs that are relevant. Since the percentage change in adjusted total user costs declined for each of the investment levels identified, the annual projected VMT growth was higher than the 1.2-percent baseline projection in all cases.

Source: Highway Economic Requirements System.

Although user costs are projected to increase in absolute terms from 2016 to 2036, they are projected to decline relative to the adjusted baseline by between 3.8 percent (at the lowest level of investment analyzed) and 6.2 percent (at the highest level of investment analyzed). Because the percentage change in adjusted total user costs declined for each investment level identified, the effective annual projected VMT growth associated with each investment level is higher than the 1.20-percent baseline projection in all cases, ranging from 1.29 percent to 1.48 percent.

Impacts of NHS Investments Modeled by HERS

As described in Chapter 1, the NHS includes the Interstate System and other routes most critical to national defense, mobility, and commerce.

This subsection examines the impacts that investment on NHS roads could have on future NHS conditions and performance, independent of spending on other Federal-aid highways. The analyses center on special HERS runs that used a database consisting only of NHS roads. The top row of each table in the exhibits that follow represents a run within which all potential improvements with a BCR of 1.0 or higher are implemented; this corresponds to the definition of the Improve Conditions and Performance scenario presented in Chapter 7.

The Maintain Avg. IRI funding level represents the spending level projected to be adequate to allow average pavement roughness on NHS roads as measured by the IRI in 2036 to match the level in 2016. Recent Spending signifies the level of spending that maintains recent spending (2012 to 2016 average in constant-dollar terms) on NHS roads. Although these two investment levels are defined in a parallel manner to the Maintain Conditions and Performance and Sustain Recent Spending scenarios presented in Chapter 7, they do not represent direct inputs to those scenarios. Those Chapter 7 scenarios seek to maintain conditions or sustain spending, respectively, on Federal-aid highways; NHS conditions and NHS spending, respectively, are not held constant. The remaining three of the six investment levels presented in the next three exhibits were selected to fill gaps between the three data points linked to specific criteria, and to extend the lower end of the range of investment levels analyzed.

Impact of Future Investment on NHS User Costs and VMT

Exhibit 10-9 presents the projected impacts of NHS investment on VMT and total average user costs on NHS roads in 2036. Across the investment levels presented, HERS allocates between $19.2 billion and $37.1 billion in average annual spending on NHS roads to system rehabilitation and between $13.8 billion and $23.7 billion in average annual spending on NHS roads to system expansion.

Average user costs are projected to be lower in 2036 than they were for the adjusted baseline ($1.291 per VMT) for all investment levels presented. When implementing all cost-beneficial projects (the highest level of investment, an annual average of $60.8 billion), average total user costs are projected to be 6.81 percent lower ($1.203 per VMT) than were adjusted baseline user costs in 2016 ($1.291 per VMT). At the Maintain Recent Spending level of investment (an annual average of $43.2 billion), average total user costs are projected to be 5.57 percent lower ($1.219 per VMT) than were adjusted baseline user costs in 2016.

VMT on the NHS is expected to rise from 1.733 trillion in 2016 to 2.322 trillion in 2036 at the highest level of investment analyzed, equating to an average annual growth rate of 1.47 percent. At the lowest level of investment analyzed, VMT is projected to rise by 1.33 percent annually to 2.258 trillion.

Exhibit 10-9 ■ HERS Investment Levels Analyzed for the National Highway System and Projected Minimum Benefit-cost Ratios, User Costs, and VMT

HERS-modeled Investment On the NHS (Average Annual Over 20 Years)			Projected NHS Indicators			
Total HERS Spending[1]	System Rehabilitation Spending	System Expansion Spending	Minimum BCR 20-year 2015 through 2036[2]	Average 2036 Total User Costs ($/VMT)[3]	Projected 2036 VMT (Trillions)[4]	Description
$60.8	$37.1	$23.7	**1.00**	$1.203	2.322	BCR≥1.0
$53.0	$31.9	$21.1	1.05	$1.210	2.305	
$45.5	$27.0	$18.5	1.24	$1.217	2.291	Maintain Avg. IRI
$43.2	$25.6	$17.6	1.32	$1.219	2.286	Recent Spending
$38.0	$22.2	$15.8	1.54	$1.226	2.272	
$33.0	$19.2	$13.8	1.79	$1.233	2.258	
			Base Year Values:	**$1.270**	**1.733**	
			Adjusted Baseline:	**$1.291**		

Note: VMT is vehicle miles traveled; HERS is Highway Economic Requirements System; BCR is benefit-cost ratio; IRI is International Roughness Index.

[1] HERS splits its available budget between system rehabilitation and system expansion based on the mix of spending it finds to be most cost-beneficial, which varies by funding level.

[2] As HERS ranks potential improvements by their estimated BCRs and assumes that the improvements with the highest BCRs will be implemented first (up until the point where the available budget specified is exhausted), the minimum BCR will naturally tend to decline as the level of investment analyzed rises.

[3] The computation of user costs includes several components (value of travel time per hour, fuel prices, fuel efficiency, truck travel as a percentage of total travel, etc.) that are assumed to change over time independently of future highway investment. The adjusted baseline applies the parameter values for 2036 to the data for 2016, so that changes in user costs attributable to future highway investment can be identified.

[4] The operation of the travel demand elasticity features in HERS cause future VMT growth to be influenced by future changes in average user costs per VMT. For this report, the model was set to assume that the baseline projections of future VMT already take into account anticipated independent future changes in user cost component values; hence, it is the changes vs. the adjusted baseline user costs that are relevant.

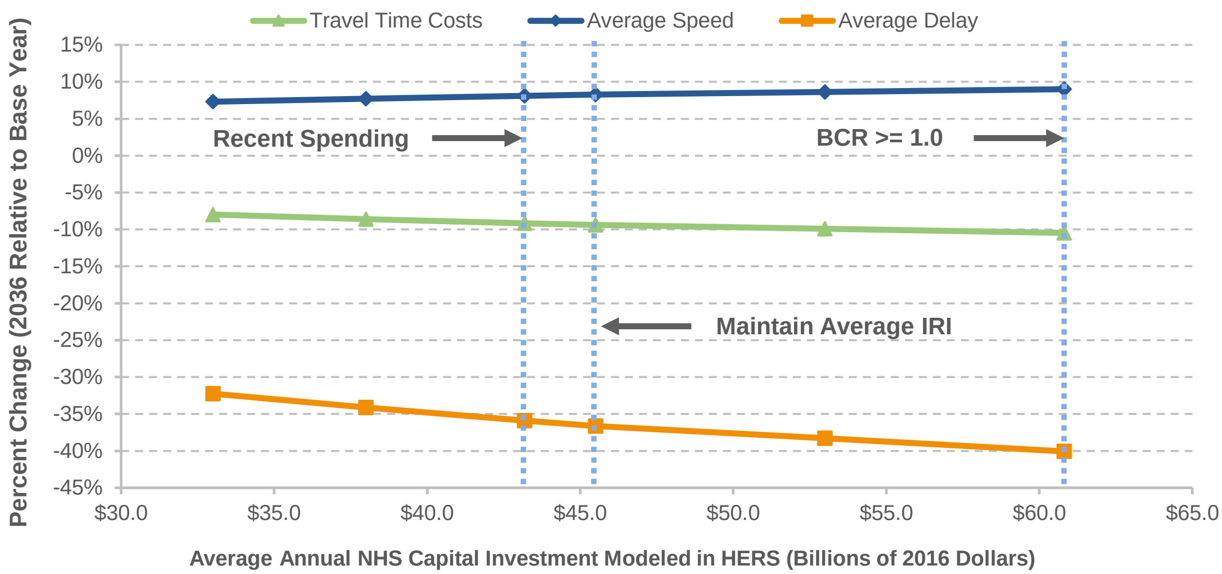
Source: Highway Economic Requirements System.

Impact of Future Investment on NHS Travel Times and Travel Time Costs

The tabular portion of *Exhibit 10-10* presents the projections of NHS averages for time-related indicators of performance, along with the spending amount that HERS allocates for NHS expansion projects (which have stronger effects on time-related indicators of performance than do preservation projects).

The graph is plotted based on the total average annual NHS investment modeled in HERS, including spending on both system rehabilitation and system expansion. For all investment levels presented in *Exhibit 10-10*, average travel speed in 2036 exceeds average travel speed in 2016 (49.9 miles per hour). The range of average travel speeds is narrow across the investment levels. At the lowest level of investment in system expansion presented in *Exhibit 10-10* (an annual average of $13.8 billion), the average travel speed in 2036 is projected to be 53.5 miles per hour. At the highest level of investment in system expansion (an annual average of $23.7 billion), the average travel speed in 2036 is projected to be 54.4 miles per hour.

Exhibit 10-10 ■ Projected Impact of Future Investment Levels on 2036 Highway Speed, Travel Delay, and Travel Time Costs on the National Highway System



HERS-modeled Investment on the NHS Average Annual Spending (Billions of 2016 Dollars)		Projected 2036 Performance Measures on the NHS				
			Percent Change Relative to Base Year			
Total	**System Expansion[1]**	**Average Speed (mph)**	**Average Speed**	**Average Delay per VMT**	**Travel Time Costs per VMT[2]**	**Description**
$60.8	$23.7	54.4	9.0%	-40.0%	-10.5%	BCR ≥ 1.0
$53.0	$21.1	54.2	8.6%	-38.3%	-9.9%	
$45.5	$18.5	54.0	8.3%	-36.6%	-9.4%	Maintain Avg. IRI
$43.2	$17.6	53.9	8.1%	-35.9%	-9.2%	Recent Spending
$38.0	$15.8	53.7	7.7%	-34.1%	-8.6%	
$33.0	$13.8	53.5	7.3%	-32.2%	-8.0%	
	Base Year Values:	**49.9**				

Note: VMT is vehicle miles traveled; HERS is Highway Economic Requirements System; IRI is International Roughness Index; BCR is benefit-cost ratio.

[1] The amounts shown represent only the portion of HERS-modeled spending directed toward system expansion, rather than system rehabilitation. Other types of spending can affect these indicators as well.

[2] Travel time costs are affected by an assumption that the value of time will increase by 1.0 percent in real terms each year. Hence, costs would rise even if travel time remained constant.

Sources: Highway Economic Requirements System; Highway Statistics 2016, Table VM-1.

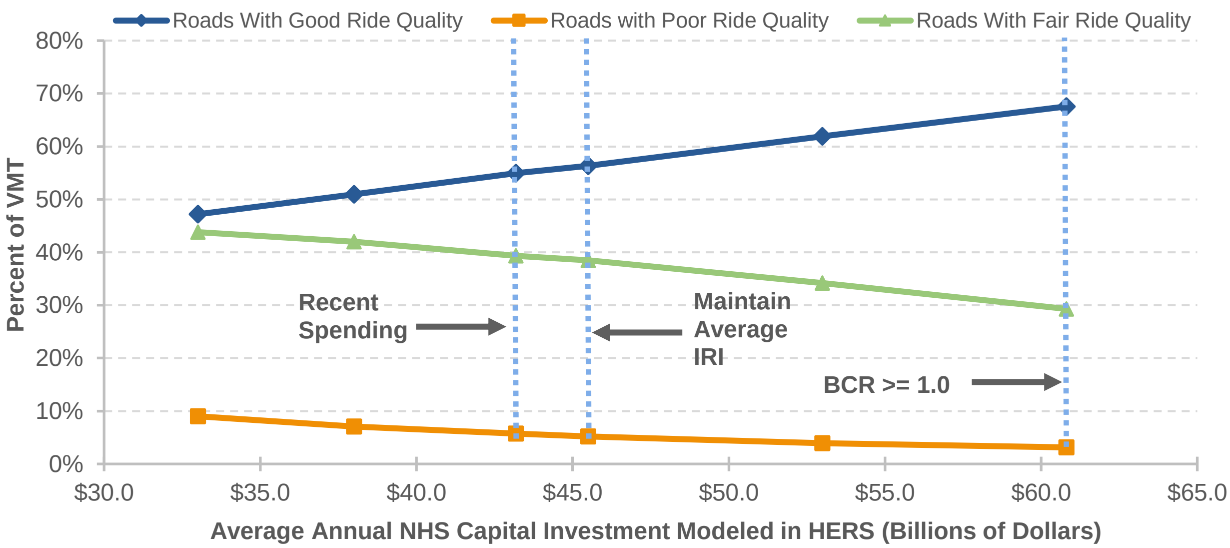
The global increase in average travel speed across investment levels corresponds to large decreases in average delay per VMT across investment levels. At the highest level of investment in system expansion, average delay per VMT in 2036 is projected to be 40.0 percent lower than it was in 2016. At the lowest level of investment in system expansion presented in the exhibit, average delay per VMT in 2036 is projected to be 32.2 percent lower than it was in 2016.

Travel time costs per VMT in 2036 are projected to decrease across the investment levels presented. Travel time costs per VMT in 2036 are projected to decrease by 10.5 percent relative to 2016 at the highest investment level and to decrease by 8.0 percent at the lowest level of investment.

Impact of Future Investment on NHS Pavement Ride Quality

The tabular portion of *Exhibit 10-11* shows the portion of modeled NHS spending that HERS allocates to rehabilitation projects (which influence average pavement quality more than do expansion projects). The graph is plotted based on total average annual NHS investment modeled in HERS, including spending on both system rehabilitation and system expansion. At the highest level of investment presented in *Exhibit 10-11* (an annual average of $37.1 billion allocated to system rehabilitation), the model projects that pavements with an IRI above 170 (the criterion presented in Chapter 6 for rating ride quality as "poor") will carry 3.1 percent of the VMT on the NHS, down from the 11.3 percent estimated for 2016.

Exhibit 10-11 ■ Projected Impact of Future Investment Levels on 2036 Pavement Ride Quality Indicators for the National Highway System



HERS-modeled Investment on the NHS Average Annual Spending (Billions of 2016 Dollars)		Projected 2036 Condition Measures on the NHS[1]					
		Percent of VMT on Roads With Ride Quality of:			Average IRI (VMT-weighted)		
Total	**System Rehabilitation[2]**	**Good (IRI<95)**	**Fair (IRI 95 to 170)**	**Poor (IRI>170)**	**Inches Per Mile**	**Change Relative to Base Year**	**Description**
$60.8	$37.1	67.6%	29.3%	3.1%	89.1	-9.8%	BCR ≥ 1.0
$53.0	$31.9	61.9%	34.2%	3.9%	93.7	-5.2%	
$45.5	$27.0	56.3%	38.5%	5.2%	98.8	**0.0%**	Maintain Avg. IRI
$43.2	$25.6	55.0%	39.3%	5.7%	100.3	1.5%	Recent Spending
$38.0	$22.2	51.0%	42.0%	7.1%	104.5	5.8%	
$33.0	$19.2	47.2%	43.8%	9.0%	109.2	10.5%	
Base Year Values:		**59.6%**	**29.1%**	**11.3%**	**98.8**		

Note: VMT is vehicle miles traveled; HERS is Highway Economic Requirements System; IRI is International Roughness Index; BCR is benefit-cost ratio.

[1] As discussed in Chapter 6, IRI values of 95 through 170 inches per mile are classified as "fair," lower IRI values are classified as "good," and higher IRI values are classified as "poor."

[2] The amounts shown represent only the portion of HERS-modeled spending directed toward system rehabilitation, rather than system expansion. Other types of spending can affect these indicators as well.

Source: Highway Economic Requirements System.

At the highest level of investment, HERS also projects that pavements with an IRI below 95 (the criterion presented in Chapter 6 for rating ride quality as "good") will carry 67.6 percent of the VMT on the NHS, up from the 59.6 percent estimated for 2016. The model projects a declining share of NHS travel on pavements with "fair" ride quality, from 43.8 percent at the lowest investment level to 29.3 percent at the highest investment level. The latter is virtually the same as the NHS travel on pavements with "fair" ride quality at 29.1 percent in 2016. It is projected that the average IRI of the NHS system would rise to 89.1 at the highest investment level, achieving the classification of providing "good" ride quality at the aggregate level.

The model finds it to be cost-beneficial to reduce the VMT-weighted share of pavements with poor ride quality from 11.3 percent in 2016 to 3.1 percent in 2036 but predicts the costs of further reductions would exceed the benefits. A key factor leading to this result is that some improvements are not cost-beneficial until IRI rises above the threshold for "fair" ride quality by a sufficient margin. Thus, for some roads with an IRI above 170, improvements would not generate benefits exceeding costs.

Even at the lowest level of investment presented in *Exhibit 10-11* (an annual average of $19.2 billion allocated to system rehabilitation), the model projects that the share of NHS travel carried by pavements with an IRI above 170 would decline from 11.3 percent in 2016 to 9.0 percent in 2036. At this investment level, average IRI would increase to 109.2, and the share of NHS travel on pavements with an IRI below 95 would decline to 47.2 percent.

Impacts of Interstate System Investments Modeled by HERS

The Interstate System, unlike the broader NHS of which it is a part, has standard design and signage requirements, making it the most recognizable subset of the highway network. This section examines the impacts that investment in the Interstate System could have on future Interstate System conditions and performance, independently of spending on other Federal-aid highways. The analyses center on special HERS runs that used a database consisting only of Interstate System roads.

As was the case for the NHS analyses presented earlier, the top row in each table represents a run within which all potential improvements with a BCR of 1.0 or higher are implemented; this corresponds to the definition of the Improve Conditions and Performance scenario presented in Chapter 7. The Recent Spending row in each table represents a run at which the average annual investment level over 20 years matches the average annual level from 2012 to 2016 in constant-dollar terms by all levels of government combined. The remaining investment levels presented in the next three exhibits reflect analyses in which a fixed amount of investment occurred in each year; these were arbitrarily selected simply to show a wide range of alternatives.

Impact of Future Investment on Interstate User Costs and VMT

Exhibit 10-12 presents the projected impacts of highway investment on VMT and total average user costs on Interstate highways in 2036, along with the amount that HERS allocates to Interstate projects. Across the Interstate highway investment levels presented, HERS allocates between $6.3 billion and $16.8 billion in average annual spending to system rehabilitation and between $5.7 billion and $12.4 billion in average annual spending to system expansion.

Average user costs are projected to be lower in 2036 than the adjusted baseline ($1.178 per VMT) for all investment levels presented. At the highest level of investment presented in *Exhibit 10-12* (an annual average of $29.2 billion), average total user costs are projected to be 5.80 percent lower ($1.110 per VMT) in 2036 than they were in 2016. At the recent (2012 to 2016) level of investment (an annual average of $18.4 billion), average total user costs are projected to be 3.41 percent lower ($1.138 per VMT) in 2036 than they were in 2016.

Interstate VMT is projected to rise from 0.799 trillion in 2016 to 1.081 trillion in 2036 at the highest level of investment analyzed, equating to an average annual growth rate of 1.52 percent. At the lowest level of investment analyzed, Interstate VMT is projected to rise by 1.33 percent annually to 1.040 trillion.

Exhibit 10-12 ■ HERS Investment Levels Analyzed for the Interstate System and Projected Minimum Benefit-cost Ratios, User Costs, and VMT

HERS-modeled Investment On the Interstate System			Projected Interstate Indicators			
Average Annual Over 20 Years						
Total HERS Spending[1]	System Rehabilitation Spending	System Expansion Spending	Minimum BCR 20-year 2017 through 2036[2]	Average 2036 Total User Costs ($/VMT)[3]	Projected 2036 VMT (Trillions)[4]	Description
$29.2	$16.8	$12.4	**1.00**	$1.110	1.081	BCR ≥ 1.0
$21.3	$11.8	$9.5	1.00	$1.131	1.068	
$18.4	$10.0	$8.4	1.24	$1.138	1.062	Recent Spending
$15.0	$8.0	$7.0	1.70	$1.148	1.052	
$12.0	$6.3	$5.7	2.21	$1.161	1.040	
			Base Year Values:	**$1.149**	**0.799**	
			Adjusted Baseline:	**$1.178**		

Note: VMT is vehicle miles traveled; HERS is Highway Economic Requirements System; BCR is benefit-cost ratio.

[1] HERS splits its available budget between system rehabilitation and system expansion based on the mix of spending it finds to be most cost-beneficial, which varies by funding level.

[2] As HERS ranks potential improvements by their estimated BCRs, and assumes that the improvements with the highest BCRs will be implemented first (up until the point where the available budget specified is exhausted), the minimum BCR will naturally tend to decline as the level of investment analyzed rises.

[3] The computation of user costs includes several components (value of travel time per hour, fuel prices, fuel efficiency, truck travel as a percent of total travel, etc.) that are assumed to change over time independent of future highway investment. The adjusted baseline applies the parameter values for 2036 to the data for 2016 so that changes in user costs attributable to future highway investment can be identified.

[4] The operation of the travel demand elasticity features in HERS causes future VMT growth to be influenced by future changes in average user costs per VMT. For this report, the model was set to assume that the baseline projections of future VMT already take into account anticipated independent future changes in user cost component values; hence, it is the changes vs. the adjusted baseline user costs that are relevant.

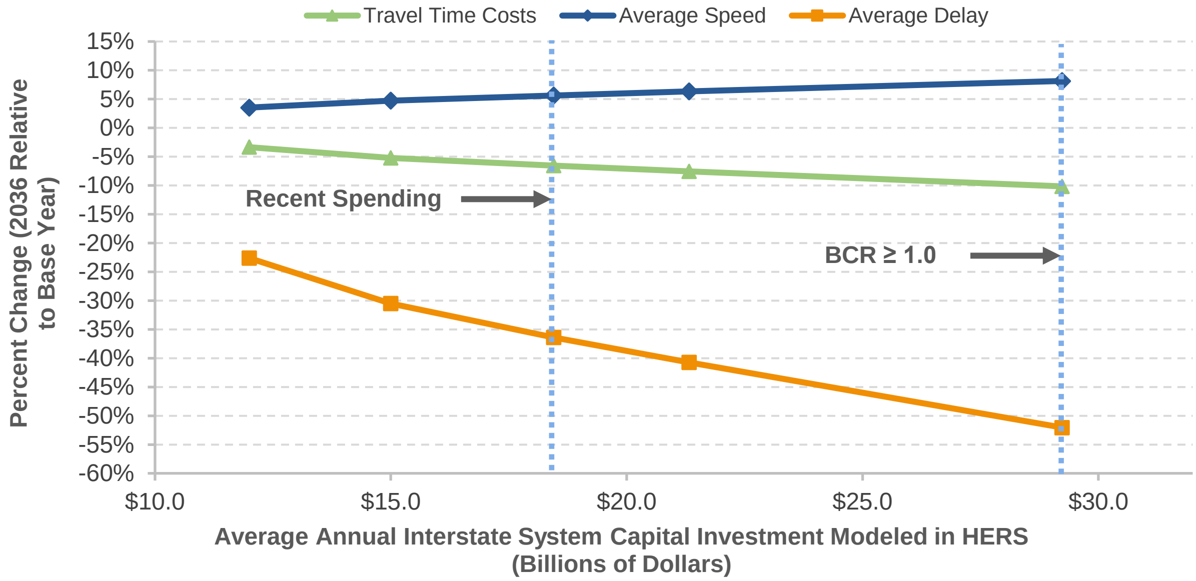
Source: Highway Economic Requirements System.

Impact of Future Investment on Interstate System Travel Times and Travel Costs

The tabular portion of *Exhibit 10-13* presents the projections of Interstate System averages for time-related indicators of performance, along with the amount that HERS allocates for Interstate System expansion projects (which have a relatively larger impact on travel time than do system rehabilitation projects).

The graph is plotted based on total average annual Interstate investment modeled in HERS, including spending on both system rehabilitation and system expansion. Across all investment levels presented in *Exhibit 10-13*, average speed on the Interstate System is projected to be higher in 2036 than was its 2016 level (62.7 miles per hour). At the highest level of investment presented in *Exhibit 10-13* (average annual investment in system expansion of $12.4 billion), average Interstate highway travel speed is projected to be 8.1 percent higher (67.8 miles per hour) in 2036 than it was in 2016. At the lowest level of investment presented in *Exhibit 10-13* (average annual investment in system expansion of $5.7 billion), average Interstate highway travel speed is projected to be 3.5 percent higher (64.9 miles per hour) in 2036 than it was in 2016.

Exhibit 10-13 ■ Projected Impact of Future Investment Levels on 2036 Highway Speed, Travel Delay, and Travel Time Costs on the Interstate System



HERS-modeled Investment on Interstate Highways		Projected 2036 Performance Measures on Interstate Highways				
Average Annual Spending (Billions of 2016 Dollars)			Percent Change Relative to Base Year			
Total	System Expansion[1]	Average Speed (mph)	Average Speed	Average Delay per VMT	Travel Time Costs per VMT	Description
$29.2	$12.4	67.8	8.1%	-52.0%	-10.2%	BCR ≥ 1.0
$21.3	$9.5	66.6	6.3%	-40.7%	-7.6%	
$18.4	$8.4	66.2	5.6%	-36.4%	-6.5%	Recent Spending
$15.0	$7.0	65.6	4.7%	-30.5%	-5.2%	
$12.0	$5.7	64.9	3.5%	-22.6%	-3.4%	
	Base Year Values:	**62.7**				

Note: VMT is vehicle miles traveled; HERS is Highway Economic Requirements System; BCR is benefit-cost ratio.

[1] The amounts shown represent only the portion of HERS-modeled spending directed toward system expansion, rather than system rehabilitation. Other types of spending can affect these indicators as well.

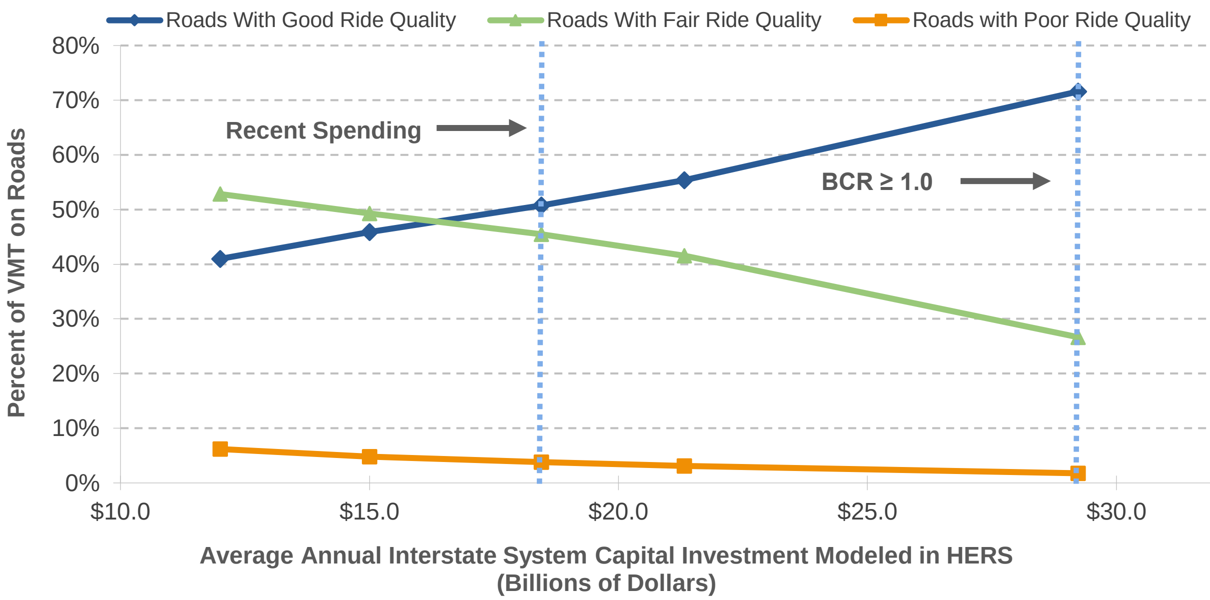
Sources: Highway Economic Requirements System; Highway Statistics 2016, Table VM-1.

The global increase in average travel speed across investment levels corresponds to large decreases in average delay per VMT across investment levels. At the highest level of investment presented in *Exhibit 10-13*, average delay per VMT in 2036 is projected to be 52.0 percent lower than it was in 2016. At the lowest level of investment presented in *Exhibit 10-13*, average delay per VMT in 2036 is projected to be 22.6 percent lower than it was in 2016. Travel time costs per VMT in 2036 are projected to decrease by 10.2 percent relative to 2016 at the highest investment level and to decrease by 3.4 percent at the lowest level of investment.

Impact of Future Investment on Interstate Pavement Ride Quality

The tabular portion of *Exhibit 10-14* shows the amounts of Interstate System spending that HERS allocates to rehabilitation projects (which influence average pavement quality more than do expansion projects). The graph is plotted based on the total average annual Interstate investment modeled in HERS, including spending on both system rehabilitation and system expansion. Across all investment levels presented in *Exhibit 10-14*, the model projects that the share of pavements with an IRI below 95 (the criterion described in Chapter 6 for rating ride quality as "good") would be below that of the corresponding share in 2016 (75.3 percent). These results suggest that placing more emphasis on reducing the percentage of VMT on Interstate highways with "poor" ride quality would be more economically efficient than focusing on further increasing the share with "good" ride quality. HERS projects that it would be cost-beneficial to halve the share of pavements with "poor" ride quality from 3.6 percent in 2016 to 1.8 by 2036. Further reductions below this point do not appear to be economically justified, as HERS assumes that the effects of increasing pavement roughness on free-flow speed and vehicle operating costs are modest until after IRI rises to a relatively high level.

Exhibit 10-14 ■ Projected Impact of Future Investment Levels on 2036 Pavement Ride Quality Indicators for the Interstate System



HERS-modeled Investment on Interstate Highways		Projected 2036 Condition Measures Interstate Highways[1]					
Average Annual Spending (Billions of 2016 Dollars)		Percent of VMT on Roads with Ride Quality of:			Average IRI (VMT-Weighted)		
Total	System Rehabilitation[2]	Good (IRI<95)	Fair (IRI 95 to 170)	Poor (IRI>170)	Inches Per Mile	Change Relative to Base Year	Description
$29.2	$16.8	71.6%	26.6%	1.8%	84.2	1.9%	BCR ≥ 1.0
$21.3	$11.8	55.4%	41.5%	3.1%	95.0	15.0%	
$18.4	$10.0	50.7%	45.5%	3.8%	98.1	18.8%	Recent Spending
$15.0	$8.0	45.9%	49.3%	4.8%	102.3	23.8%	
$12.0	$6.3	41.0%	52.8%	6.2%	107.4	30.0%	
	Base Year Values:	**75.3%**	**21.1%**	**3.6%**	**82.6**		

Note: VMT is vehicle miles traveled; HERS is Highway Economic Requirements System; IRI is International Roughness Index; BCR is benefit-cost ratio.

[1] As discussed in Chapter 6, IRI values of 95 through 170 inches per mile are classified as "fair," lower IRI values are classified as "good," and higher IRI values are classified as "poor."

[2] The amounts shown represent only the portion of HERS-modeled spending directed toward system rehabilitation, rather than system expansion. Other types of spending can affect these indicators as well.

Source: Highway Economic Requirements System.

At the highest level of investment presented in *Exhibit 10-14* (an annual average of $16.8 billion allocated to system rehabilitation), the model projects average pavement roughness on the Interstate System to be 1.9 percent higher in 2036 than it was in 2016. These results suggest that it would not be cost-effective to keep the average VMT-weighted IRI of the Interstate System at its 2016 level of 82.6 (well into the "good" range), and that allowing it to rise slightly to 84.2 would be economically advantageous.

Impacts of Investments Modeled by NBIAS

The expenditures modeled in NBIAS pertain only to bridge system rehabilitation; expenditures associated with bridge system expansion are modeled separately as part of the capacity expansion analysis in HERS. The NBIAS-modeled investments presented here should be considered as additive to the HERS-modeled investments presented earlier: each capital investment scenario presented in Chapter 7 combines one HERS analysis with one NBIAS analysis and makes adjustments to account for nonmodeled spending.

Bridge Investment Levels Analyzed

Exhibits 10-15 through *10-18* examine all bridges, bridges on Federal-aid highways, NHS bridges, and Interstate System bridges, respectively. The top row in each of these next four exhibits represents the level of investment at which the Economic Investment Backlog would be eliminated (i.e., all projects with an estimated BCR of 1.0 or higher would be implemented). These are labeled as either "Improve C&P" (for all bridges) or "BCR≥1.0" (for the three subsets of bridges presented) and reflect that the investment level for all bridges feeds directly into the Improve Conditions and Performance scenario in Chapter 7, whereas the levels for bridge subsets are defined in a comparable manner but do not directly feed into that scenario.

Each of the next four exhibits also contains a row for the level of investment at which the deck area-weighted share of bridges in poor condition in 2036 would match that in 2016 (labeled as Maintain C&P for the all-bridges value that feeds into the Maintain Conditions and Performance scenario in Chapter 7 and Maintain % Poor for the subsets of bridges). Each also contains a row corresponding to average annual spending on the types of capital investments modeled in NBIAS (labeled as Recent Spending).

The remaining rows in these exhibits were selected to fill gaps between the three data points linked to specific scenarios, and to extend the lower end of the range of investment levels analyzed.

Bridge Performance Measures in *Exhibits 10-15* to *10-18*

Exhibits 10-15 to *10-18* provide three metrics of bridge performance:

- Percentage of bridges (weighted by deck area) in "good," "fair," and "poor" condition (the percentage in poor condition is used in computing the Maintain Conditions and Performance scenario in Chapter 7)
- Average Health Index
- Economic Investment Backlog (used in computing the Improve Conditions and Performance scenario in Chapter 7)

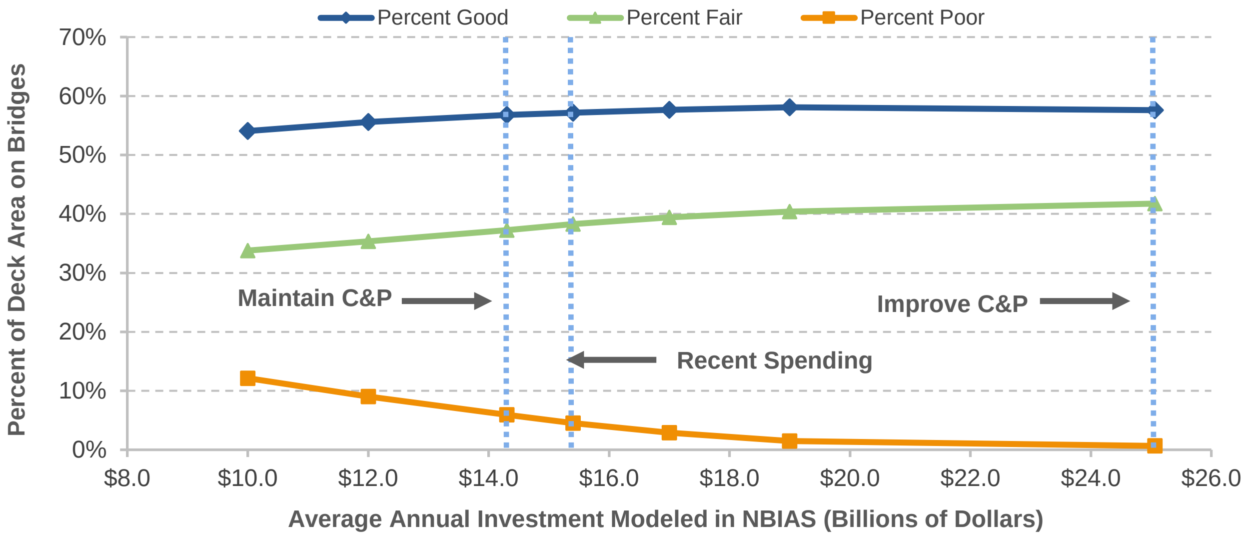
As described in Chapter 6, bridges in "good," "fair," and "poor" condition are defined by the degree of deterioration of the three major bridge components: deck, superstructure, and substructure. For a bridge to be classified as in "good" condition, all three major bridge components must be rated "good." For a bridge to be classified as in "poor" condition, at least one bridge element must be rated "poor." All other bridges are classified as in "fair" condition. The average Health Index metric is a ranking system (0–100) for bridge elements typically used in the context of decision-making for bridge preventive maintenance, with 0 being the worst condition and 100 being the best. To aggregate the element-level result to the bridge level (i.e., assign a value for the Health Index), a weight is assigned to each bridge element according to the economic consequences of its failure, and then an average of all the weighted elements is calculated. Thus, an element for which a failure has relatively little economic effect would receive less weight than an element for which a failure could result in closing the bridge. In general, the lower the Health Index, the higher the priority for rehabilitation or maintenance of the structure, although other factors also are instrumental in determining priority of work on bridges.

The Economic Investment Backlog metric represents the combined cost of all corrective actions for which NBIAS estimates implementation would be cost-beneficial. Consistent with the HERS analysis, implementing all cost-beneficial corrective actions in NBIAS would not necessarily mean that no bridges would remain in poor condition; rather, implementing all cost-beneficial corrective actions in NBIAS would indicate that it would not be cost-beneficial to take any further corrective actions.

Impacts of Systemwide Investments Modeled by NBIAS

As indicated in *Exhibit 10-2*, of the $106.9 billion average annual investment in highways from 2012 to 2016 (in 2016 constant dollars), $15.4 billion (14.4 percent) was used for bridge system rehabilitation. For investments of the types modeled by NBIAS, *Exhibit 10-15* shows how the total amount invested over the 20-year analysis period influences the bridge performance levels projected for the final year, 2036. At $15.4 billion, the investment level feeding into the Sustain Recent Spending scenario presented in Chapter 7, projected performance for 2036 would improve relative to 2016 for each performance measure considered. The share of bridges classified as in "poor" condition would decrease from 6.0 percent to 4.5 percent, whereas the share of bridges classified as in "good" condition would increase from 46.0 percent in 2016 to 57.2 percent in 2036. The average Health Index would rise from 92.3 to 94.5. The Economic Investment Backlog would decrease to $56.7 billion (57.0 percent below its 2016 level of $131.8 billion).

Exhibit 10-15 ■ Projected Impact of Future Investment Levels on 2036 Bridge Condition Indicators for All Bridges



NBIAS-modeled Investment on All Bridges	Projected 2036 Condition Indicators—All Bridges					Link to Chapter 7 Scenario
	Weighted by Deck Area					
Average Annual Investment (Billions of 2016 Dollars)[1]	Percent Good	Percent Fair	Percent Poor	Health Index	Economic Investment Backlog (Billions of 2016 Dollars)[1]	
$25.1	57.6%	41.8%	0.7%	95.5	$0.0	Improve C&P
$19.0	58.1%	40.4%	1.5%	95.5	$8.1	
$17.0	57.7%	39.4%	2.9%	95.2	$31.4	
$15.4	57.2%	38.3%	4.5%	94.5	$56.7	Recent Spending
$14.3	56.8%	37.3%	**6.0%**	93.9	$76.9	Maintain C&P
$12.0	55.6%	35.4%	9.0%	92.4	$119.6	
$10.0	54.1%	33.8%	12.1%	90.8	$161.1	
Base Year Values:	**46.0%**	**48.0%**	**6.0%**	**92.3**	**$131.8**	

Note: NBIAS is National Bridge Investment Analysis System.

[1] The amounts shown do not reflect system expansion needs; the bridge components of such needs are addressed as part of the HERS model analysis.

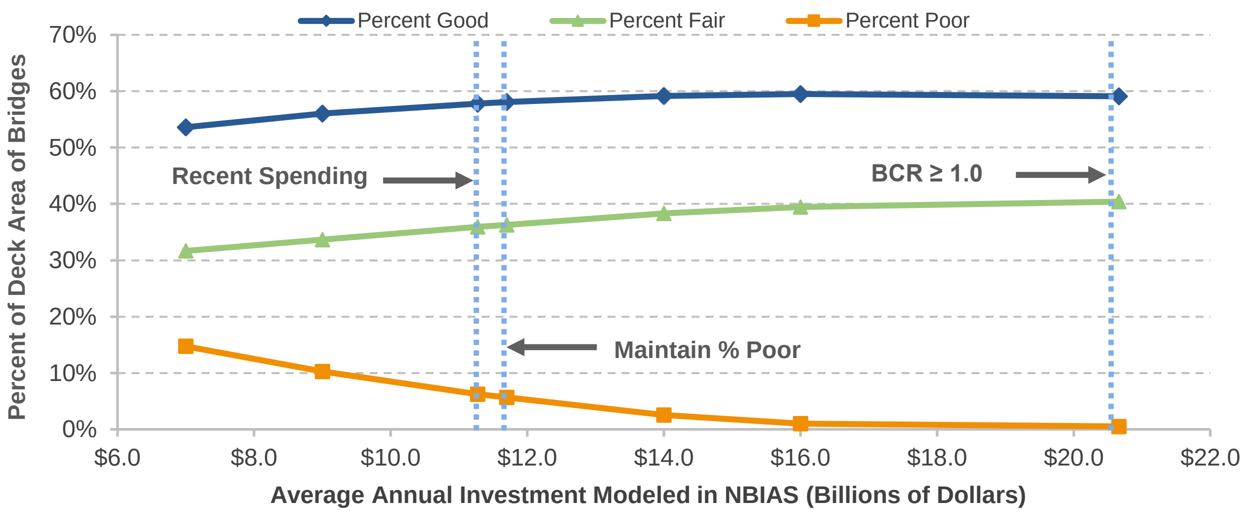
Source: National Bridge Investment Analysis System.

The highest level of spending shown in *Exhibit 10-15* averages $25.1 billion per year (this feeds into the Improve Conditions and Performance scenario in Chapter 7). This level of investment is projected to reduce the deck-area-weighted share of bridges in poor condition to 0.7 percent and to eliminate the Economic Investment Backlog for bridges by 2036. This indicates that the model does not find that completely eliminating all deficiencies would be cost-beneficial at any single point in time. In some cases, the model recommends that corrective actions be deferred; in other cases, it estimates that the benefits of replacing a bridge would be outweighed by its costs (suggesting that it should eventually be closed, diverting traffic to other available crossings).

Impacts of Federal-aid Highway Investments Modeled by NBIAS

For bridges on Federal-aid highways, *Exhibit 10-16* compares performance projections for 2036 at various levels of investment with measured performance in 2016. If spending on the types of improvements modeled in NBIAS were sustained at the recent (2012 to 2016) level of $11.3 billion (in constant dollars), performance results would be mixed. The average Health Index would rise (improve) from 92.3 to 93.7, whereas the percentage of bridges in "poor" condition weighted by deck area would rise (worsen) from 5.7 percent to 6.3 percent. Maintaining the share of bridges rated poor at 5.7 percent would require a higher level of annual investment ($11.7 billion). This finding deviates from the one identified earlier for all bridges for which sustaining spending at recent levels was projected to be more than sufficient to maintain this metric at base year levels.

Exhibit 10-16 ■ Projected Impact of Future Investment Levels on 2036 Bridge Condition Indicators for Federal-aid Highway Bridges



NBIAS-Modeled Investment on Federal-aid Bridges	Projected 2036 Condition Indicators—Federal-aid Bridges					
	Weighted by Deck Area					
Average Annual Investment (Billions of 2016 Dollars)[1]	Percent Good	Percent Fair	Percent Poor	Health Index	Economic Investment Backlog (Billions of 2016 Dollars)[1]	Description
$20.7	59.1%	40.4%	0.5%	95.5	**$0.0**	BCR ≥ 1.0
$16.0	59.5%	39.5%	1.0%	95.5	**$2.3**	
$14.0	59.1%	38.3%	2.5%	95.3	**$24.4**	
$11.7	58.1%	36.2%	**5.7%**	94.0	**$64.3**	Maintain % Poor
$11.3	57.8%	35.9%	6.3%	93.7	**$72.2**	Recent Spending
$9.0	56.0%	33.7%	10.3%	91.8	**$117.1**	
$7.0	53.6%	31.7%	14.7%	89.4	**$165.5**	
Base Year Values:	**45.3%**	**49.1%**	**5.7%**	**92.3**	**$108.8**	

Note: NBIAS is National Bridge Investment Analysis System; HERS is Highway Economic Requirements System; BCR is benefit-cost ratio.

[1] The amounts shown do not reflect system expansion needs; the bridge components of such needs are addressed as part of the HERS model analysis.

Source: National Bridge Investment Analysis System.

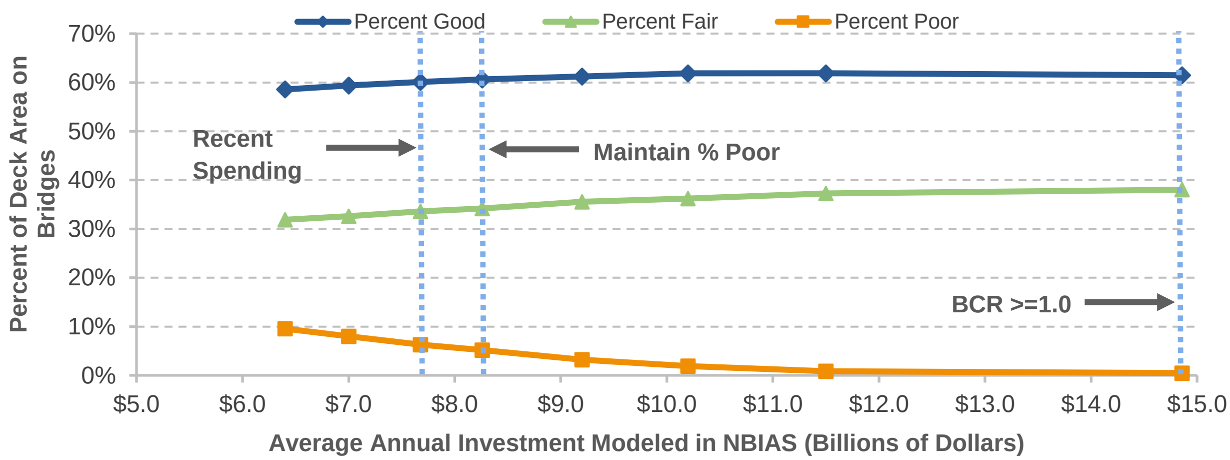
At the $20.7 billion average annual investment level consistent with the Improve Conditions and Performance scenario, NBIAS projects the percentage of bridges in "poor" condition weighted by deck area would decrease to 0.5 percent on Federal-aid highways. The Economic Investment Backlog would be reduced to zero by 2036, and the average Health Index would increase from 92.3 to 95.5.

Impacts of NHS Investments Modeled by NBIAS

The impact of various funding levels on the performance of the bridges on the NHS is shown in *Exhibit 10-17*. If spending on types of improvements modeled in NBIAS on NHS bridges was sustained at the recent (2012–2016) level of $7.7 billion in constant-dollar terms, the deck-area-weighted share of bridges in "poor" condition would increase from 5.2 percent in 2016 to 6.3 percent in 2036. The average annual investment needed to maintain this indicator at its 2016 level is higher at $8.3 billion. This finding deviates from the one identified above for all bridges for which spending in 2016 was estimated to be above the level needed to maintain this metric at base year levels.

The highest level of investment analyzed, $14.9 billion, is projected to reduce the Economic Investment Backlog to zero by 2036. The percentage of bridges in "poor" condition would decrease from 5.2 in 2016 to 0.5 percent in 2036. The average Health Index would increase from 92.3 to 95.6 during the same period.

Exhibit 10-17 ■ Projected Impact of Future Investment Levels on 2036 Bridge Condition Indicators for Bridges on the National Highway System



NBIAS-Modeled Investment on NHS Bridges	Projected 2036 Condition Indicators—NHS Bridges					
	Weighted by Deck Area					
Average Annual Investment (Billions of 2016 Dollars)[1]	Percent Good	Percent Fair	Percent Poor	Health Index	Economic Investment Backlog (Billions of 2016 Dollars)[1]	Description
$14.9	61.5%	38.0%	0.5%	95.6	**$0.0**	BCR>=1.0
$11.5	61.9%	37.3%	0.9%	95.6	**$0.5**	
$10.2	61.9%	36.2%	1.9%	95.5	**$11.4**	
$9.2	61.2%	35.5%	3.2%	95.1	**$25.5**	
$8.3	60.6%	34.2%	**5.2%**	94.2	**$43.4**	Maintain % Poor
$7.7	60.1%	33.6%	6.3%	93.7	**$54.3**	Recent Spending
$7.0	59.4%	32.6%	8.0%	92.9	**$68.5**	
$6.4	58.6%	31.9%	9.6%	92.1	**$80.7**	
Base Year Values:	**44.3%**	**50.5%**	**5.2%**	**92.3**	**$75.3**	

[1] The amounts shown do not reflect system expansion needs; the bridge components of such needs are addressed as part of the HERS model analysis.

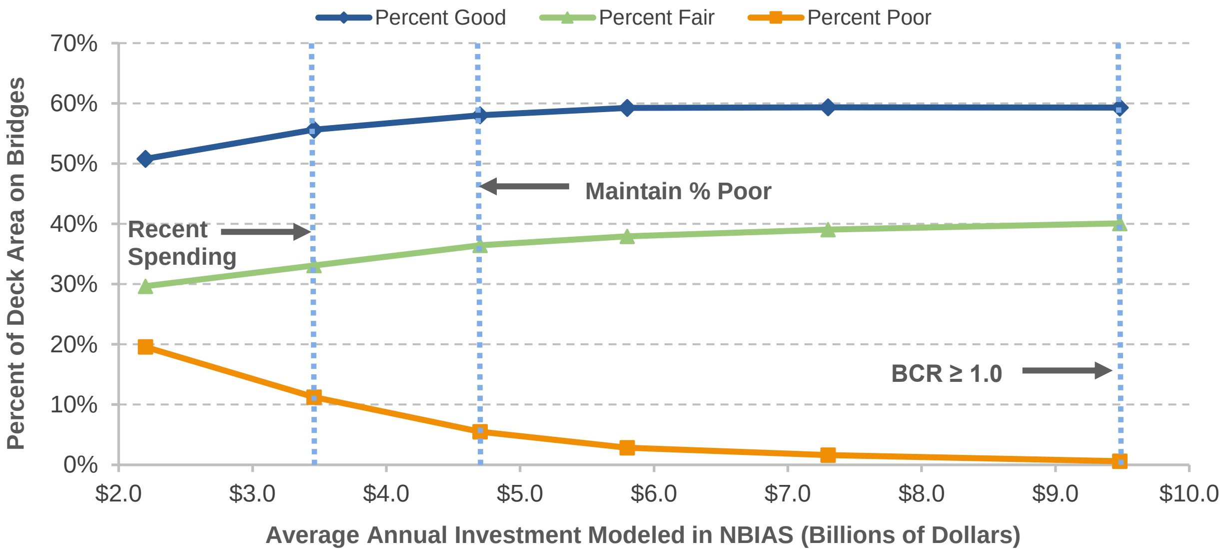
Source: National Bridge Investment Analysis System.

Impacts of Interstate System Investments Modeled by NBIAS

Exhibit 10-18 shows the impact of varying funding levels on the performance of bridges on the Interstate System. If average annual spending on types of improvements modeled in NBIAS on Interstate bridges were sustained at the recent (2012–2016) level of $3.5 billion in constant-dollar terms, the share of bridges rated as poor would increase from 5.5 percent in 2016 to 11.2 percent in 2036, weighted by deck area. By 2036, the average Health Index would fall from 91.9 to 91.4, and the Economic Investment Backlog would increase from $42.1 billion in 2016 to $47.2 billion in 2036. An average annual investment of $4.7 billion would be needed to keep the deck area-weighted share of bridges in poor condition from rising above its 2016 level in 2036. For the highest level of investment analyzed (implementing all cost-beneficial projects identified), the average annual investment level of $9.5 billion is estimated to be sufficient to reduce the Economic Investment

Backlog to zero by 2036, decrease the deck area-weighted share of bridges rated as poor to 0.6 percent, and increase the average Health Index to 95.5.

Exhibit 10-18 ■ Projected Impact of Alternative Investment Levels on 2036 Bridge Condition Indicators for Interstate Bridges



NBIAS-modeled Investment on Interstate Bridges	Projected 2036 Condition Indicators—Interstate Bridges					
	Weighted by Deck Area					
Average Annual Investment (Billions of 2016 Dollars)[1]	Percent Good	Percent Fair	Percent Poor	Health Index	Economic Investment Backlog (Billions of 2016 Dollars)[1]	Description
$9.5	59.3%	40.1%	0.6%	95.5	**$0.0**	BCR ≥ 1.0
$7.3	59.3%	39.1%	1.6%	95.5	**$1.2**	
$5.8	59.2%	37.9%	2.8%	95.3	**$8.4**	
$4.7	58.0%	36.4%	**5.5%**	94.1	**$23.6**	Maintain % Poor
$3.5	55.6%	33.1%	11.2%	91.4	**$47.2**	Recent Spending
$2.2	50.8%	29.6%	19.6%	87.0	**$80.3**	
Base Year Values:	**38.8%**	**55.7%**	**5.5%**	**91.9**	**$42.1**	

Note: NBIAS is National Bridge Investment Analysis System; BCR is benefit-cost ratio.

[1] The amounts shown do not reflect system expansion needs; the bridge components of such needs are addressed as part of the HERS model analysis.

Source: National Bridge Investment Analysis System.

Impacts of Investment – Transit

This section examines how different types and levels of annual capital investments would likely affect transit system condition and performance by 2036. It begins with an overview of the types of capital spending projected by the Federal Transit Administration's (FTA's) Transit Economic Requirements Model (TERM). The section then examines how variations in the level of annual capital spending are likely to affect future transit conditions and performance.

This edition of the C&P Report introduces a new cost-effectiveness optimization feature in TERM that affects the way TERM forecasts reinvestment needs. The new feature optimizes prioritization in the queue of assets to be replaced or rehabbed.

Applying this cost-effectiveness optimization to previous C&P Reports results in year-20 backlogs that are smaller than previously estimated. However, the size of the backlog at year 20 is not necessarily smaller in constant dollars than the backlog at year 0, because the size of the backlog is a function of the annual average investment applied to TERM for replacement and rehabilitation needs. Other factors include inflation and changes in the National Inventory between editions of the C&P Report.

KEY TAKEAWAYS

- The recent level of current investment in transit asset preservation ($11.6 billion) is roughly the amount required to maintain the SGR backlog at currently levels.
- If the recent level of preservation investment ($11.6 billion) is maintained, the average national asset condition is expected to decay from the adequate range to the marginal range by 2036.
- The recent level of investment in service expansion ($7.2 billion) is sufficient to accommodate an average annual ridership increase of 1.7 percent, higher than the 15 -year historical rate of 1.5 percent. This might result in less crowded conditions in stations, trains, and buses, and increased operating speeds.
- Recent investment levels are higher than required to accommodate the low ridership growth scenario (1.3 percent). If ridership grows at the 1.28–1.82-percent range (±0.3 percent around the 15-year historical growth rate), investment in expansion in the $705–$8.0 billion range would be needed to avoid deterioration of service quality.

A detailed discussion of the new cost-effectiveness optimization feature is presented later in in this section, under Impacts of Systemwide Investments Modeled by TERM.

Impacts of Systemwide Investments Modeled by TERM

This section uses TERM analyses to assess how various levels of investment in the preservation and expansion of the Nation's transit asset base can be expected to influence transit conditions and performance over the next 20 years. A key objective is to place a broad range of potential future investment levels—and the consequences of those levels of investment—within the context of both the current expenditures on transit preservation and expansion and some potential investment goals (e.g., attainment of an SGR within 20 years). More specifically, these analyses consider the impact of different levels of transit capital expenditures on the following:

- Preservation Investments: Average condition rating of U.S. transit assets and SGR backlog; and
- Expansion Investments: Additional ridership (boardings) capacity.

Impact of Preservation Investments on Transit Backlog and Conditions

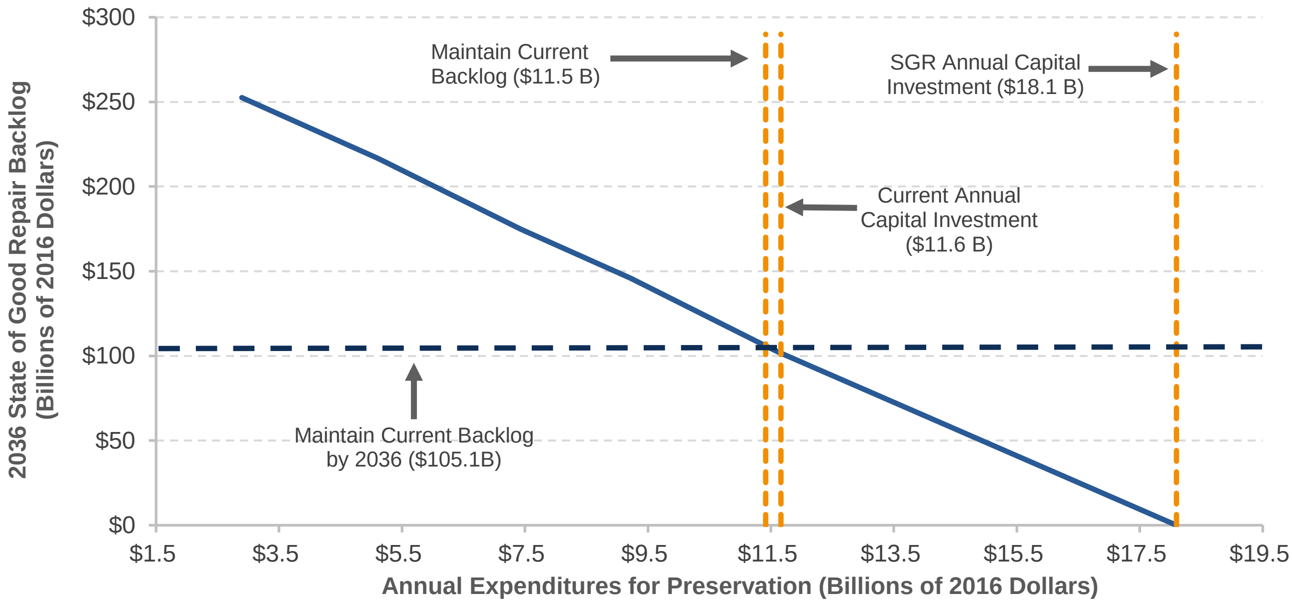
This subsection considers the expected impact of varying levels of aggregate capital reinvestment by all levels of government on the future investment backlog and physical condition (as of 2036) for the Nation's existing stock of transit assets.

Transit Backlog

The 2010 C&P Report introduced the concept of reinvestment backlog as an indication of the amount of near-term investment that would be needed to replace assets that are beyond their expected useful lifetime. Reinvestment backlog focuses attention on assets that are in the worst condition rather than on the average condition of all assets, which is reported in *Exhibit 10-19* and had been the primary measure in previous editions. This additional perspective is needed because average condition has become less meaningful in the current environment as an indicator of the health of the current system, with high levels of investment in new assets for transit system expansion raising the systemwide averages independent of the state of existing transit assets. Reinvestment backlog is a measure of the potential need for investment in infrastructure preservation. TERM estimates that reinvestment backlog is $105.1 billion (see Chapter 7).

Exhibit 10-19 presents the estimated impact of differing levels of annual capital reinvestment on the expected size of the reinvestment backlog in 2036. Here the reinvestment backlog is defined as the level of investment required to bring all the Nation's assets to an SGR. This includes replacing those assets that currently exceed their useful lives ($105 billion) and completing all major rehabilitation activities and replacing assets that will exceed their useful lives during the analysis period. If future reinvestment rates are insufficient to address these ongoing reinvestment needs as they arise, the size of the backlog will increase over time. Reinvestment at a rate above that required to address new needs as they arise will ultimately result in elimination of the existing backlog. As shown in *Exhibit 10-19*, TERM analysis suggests that the recent average rate of capital reinvestment of $11.6 billion is marginally higher than that required to maintain the SGR backlog and, if sustained over the next 20 years, would result in a reinvestment backlog of roughly $102.3 billion by 2036. In contrast, increasing the annual rate of reinvestment to an average of $18.1 billion would fully eliminate the backlog by 2036. Finally, an annual level of reinvestment of roughly $11.5 billion is required to maintain the backlog at its current level.

Exhibit 10-19 ■ Impact of Preservation Investment on 2036 Transit State of Good Repair Backlog in All Urbanized and Rural Areas



Average Annual Investment (Billions of 2016 Dollars)	Average Annual Percent Change vs. 2016	Average Condition Rating in 2036	Backlog in 2036 (Billions of 2016 Dollars)	Percent Change from Current Backlog	Funding Level Description
$18.1	4.2%	2.91	$0.0	-100.0%	SGR (unconstrained, replace at 2.50)
$11.6	0.0%	2.72	$102.3	-2.7%	Sustain recent spending
$11.5	-0.1%	2.71	$105.1	0.0%	Maintain current backlog
$9.2	-2.4%	2.60	$145.8	38.7%	
$7.4	-4.8%	2.53	$174.8	66.3%	
$5.1	-9.5%	2.43	$216.5	105.9%	
$2.9	-18.9%	2.34	$252.5	140.3%	

Notes: For this report, assets are considered past their useful lives once their estimated condition in TERM falls below condition 2.50. SGR is state of good repair.

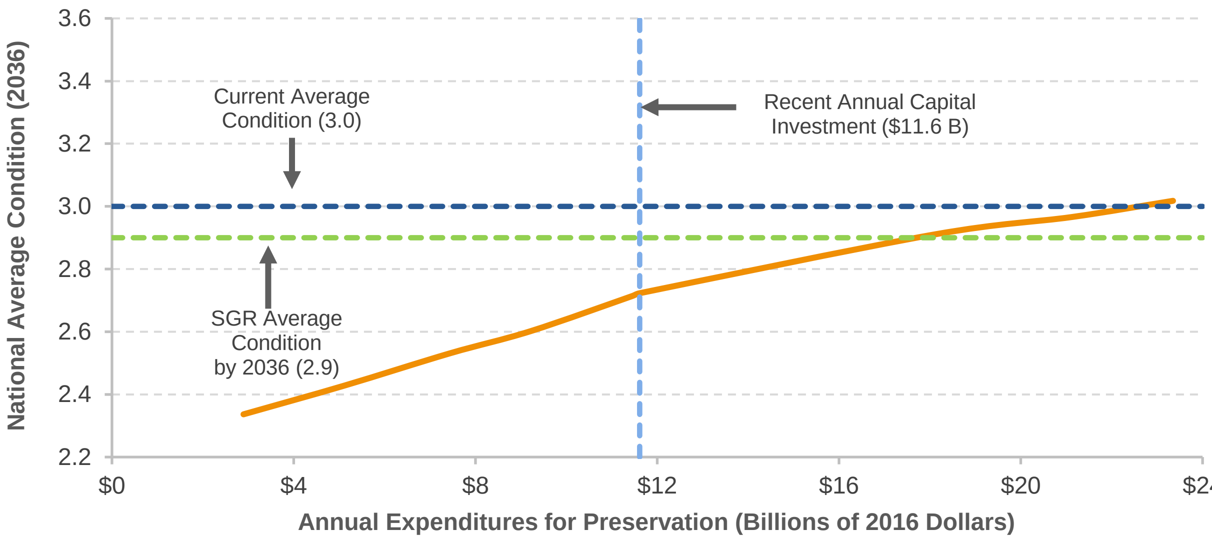
Source: Transit Economic Requirements Model.

Transit Conditions

Exhibit 10-20 presents the estimated impact of various levels of annual rehabilitation and replacement investments on the average physical condition of all existing assets nationwide as of 2036. The exhibit shows ongoing improvements to the overall condition of the Nation's existing transit asset base from increasing levels of transit capital reinvestment. Of special note is that average condition provides a measure of asset conditions taken together. Hence, despite the fact that overall conditions improve with additional expenditures, the condition of some individual assets is expected to continue to deteriorate (given the length of asset lives and the timing of their replacement cycles) while the condition of other assets improves. The value of the aggregate measure lies in providing an overall, single measure of asset conditions. Moreover, given the relationship between asset condition and asset reliability, any general improvement in overall asset conditions also can be associated with related improvements to service quality and reliability. The table portion of *Exhibit 10-20* presents the same investment and average condition information as in the chart. This table also presents the impact of reinvestment on asset conditions for five key transit asset categories (i.e., guideway and track, facilities, systems, stations, and vehicles) and the average annual percentage change in constant dollar funding from recent levels to achieve each projected condition level.

Further review of *Exhibit 10-20* allows several observations: First, almost none of the selected reinvestment rates presented (including the recent level of reinvestment, which was $11.6 billion) is sufficient to maintain aggregate conditions at or near the current national average condition rating of 3.0. Only the two highest reinvestment rates presented here of $21.1 and $23.3 billion annually (replacement at condition rating 3.0 or 2.75), are sufficient to maintain aggregate conditions at current levels. A primary factor driving this result is the ongoing expansion investment in new rail systems over the past several decades. Although this expansion investment has tended to maintain or even increase the average condition rating of assets nationwide (despite the ongoing deterioration of older assets), it also has resulted in an average condition rating that may not be sustainable in the long term (i.e., without including the influence of further expansion investments or replacing assets at an unreasonably early age).

Exhibit 10-20 ■ Impact of Preservation Investment on 2036 Transit Conditions in All Urbanized and Rural Areas



Average Annual Investment (Billions of 2016 Dollars) Total Capital Outlay	Average Annual Percent Change vs. 2016	Average Transit Conditions in 2036						Notes
		Asset Categories					All Transit Assets	
		Guideway	Facilities	Systems	Stations	Vehicles		
$23.3	6.5%	2.54	3.41	3.78	3.01	3.52	3.02	Unconstrained, replace at 3.00
$21.1	5.6%	2.51	3.40	3.68	2.97	3.41	2.97	Unconstrained, replace at 2.75
$18.1	4.2%	2.49	3.34	3.58	2.93	3.30	2.91	SGR (unconstrained, replace at 2.50)
$11.6	0.0%	2.36	2.68	3.52	2.45	3.29	2.72	Recent capital expenditures
$11.5	-0.1%	2.36	2.68	3.50	2.44	3.28	2.71	Maintain current backlog
$9.2	-2.4%	2.26	2.68	3.29	2.34	3.13	2.60	
$7.4	-4.8%	2.20	2.67	3.19	2.32	2.98	2.53	
$5.1	-9.5%	2.16	2.67	2.99	2.27	2.69	2.43	
$2.9	-18.9%	2.14	2.66	2.84	2.22	2.34	2.34	

Notes: The conditions of individual transit assets are estimated using TERM's asset decay curves, which estimate asset conditions on a scale of 5 (excellent) through 1 (poor), as described earlier in this chapter and in Appendix C of this report. The average national condition is the weighted average of the condition of all assets nationwide, weighted by the estimated replacement cost of each asset. This preservation analysis is intended to consider reinvestment needs only for existing transit assets (as of 2014), not for expansion assets to be added to the existing capital stock in future years. SGR is state of good repair.

Source: Transit Economic Requirements Model.

Second, reinvestment at roughly $18.1 billion annually is required to attain an SGR condition by 2036, and this level of reinvestment is estimated to yield an average condition value of roughly 2.91 by that year. Given the definition of the SGR Benchmark (described in greater detail in Chapter 9), which seeks to eliminate the existing investment backlog and then address all subsequent rehabilitation and replacement activities "on time" thereafter, the 2.9 value could be considered representative of the expected long-term average condition of a well-maintained and financially and economically unconstrained national transit system. Hence, an average condition rating of roughly 2.9 represents a more reasonable long-term condition target for existing transit infrastructure than the current aggregate rating of 3.0.

Another observation is that a significant level of reinvestment is required to alter the estimated 2036 average condition measure by a point or more. This result is also driven in part by a large proportion of transit assets that are either nonreplaceable (e.g., subway tunnels and stations) or assets that have expected useful lives of 80 years or more that will not require significant reinvestment over the 20-year period of this analysis (regardless of the level of reinvestment). These assets tend to contribute a high weighting in the average condition measure, making the measure somewhat insensitive to the rate of reinvestment. Note that a high proportion of reinvestment activity is focused on the replacement of those assets with relatively shorter useful lives, such as vehicles.

Finally, TERM prioritizes asset needs based on five criteria (condition, reliability, safety, operations and maintenance cost impacts, and investment cost-effectiveness) with condition having the highest weighting. Replacement and rehabilitation investments are both subject to this same prioritization scoring. Replacement needs tend to score higher, however, as they tend to reflect the needs of assets that are in poorer condition than those assets requiring rehabilitation. Therefore, rehabilitation needs tend not to be addressed until most (but far from all) replacement needs are addressed. Although TERM predicts improvement in asset condition following asset replacement, it does not currently predict an improvement in condition following asset rehabilitation. This is because TERM's decay curves are currently "responsive" to replacements (as older assets in marginal and poor condition are replaced by new assets in excellent condition). In contrast, TERM's decay curves are not currently designed to improve an asset's condition following a rehabilitation. For this reason, expenditures beyond approximately $11.6 billion on the chart increase total cost as rehabilitation projects are added, but these projects do not contribute to an increase in condition. FTA expects that "rehab-responsive" decay curves will be developed and introduced in a future C&P Report.

Prioritization and the Cost-Effectiveness Investment Criterion

TERM uses a prioritization routine to determine the order in which reinvestment needs are addressed when funding is insufficient to cover the cost of all outstanding needs. Under these circumstances, TERM completes three analyses for each year of a 20-year, constrained model run. First, it assesses all reinvestment needs for each year of analysis. Next, it assigns a priority score to each reinvestment need, using the investment criteria identified above, and then ranks these needs from highest to lowest based on the assigned priority scores. Finally, it addresses the ranked reinvestment needs, from highest to lowest, subject to the available budget for that year of analysis. Once all available funds of an analysis year have been expended, the reinvestment process ends and any unaddressed needs for that year are added to the investment backlog (potentially to be addressed in a later year of analysis).

In contrast to previous C&P Reports, which relied on four investment criteria (condition, reliability, safety, and operations and maintenance cost impacts), all constrained needs analyses in this report also include the impact of an additional cost-effectiveness criterion. Here, "cost-effectiveness" is defined as the ratio of the cost of a reinvestment need to the number of riders benefiting from that reinvestment action (e.g., the cost of a bus replacement to the number of riders using the bus). This criterion is designed to function as a proxy cost-benefit measure for each investment need and in practice tends favor moderate- to lower-cost investments that benefit larger numbers of riders.

As noted above, the prioritization routine determines the order in which reinvestment needs are addressed. Hence, any changes to that routine—including inclusion of the cost-effectiveness criterion—will also result in changes to the backlog in which reinvestment needs are addressed. This change in turn affects the mix of asset needs that are ultimately addressed, the mix of asset needs that enter backlog, and the size of the backlog itself. These impacts can be seen below in *Exhibit 10-21*. Specifically, *Exhibit 10-21* shows the impact of the cost-effectiveness criterion on the size of the SGR backlog in year 20 of a model run. This impact is shown for two different TERM models: the model used for the 23rd C&P Report (with a start year of 2014) and the one used for this current 24th edition (with a start year of 2016). For both models, the size of the backlog in year 0 of the model runs is not affected by turning the cost-effectiveness criterion on or off (as start year backlog is fixed and not influenced by the selection of prioritization criteria). However, by year 20 of each model run the cost-effectiveness criterion has clearly affected the selection of which reinvestment needs are addressed and which are delegated to the backlog. For both models, inclusion of the cost-effectiveness criterion is found to reduce the size of the year-20 backlog by roughly $7.0 billion to $10.0 billion. Given that the annual budget constraint is fully utilized by each of these model runs, it is apparent that use of the cost-effectiveness criterion leads to a more cost-efficient use of investment funds, at least in terms of backlog reduction.

Exhibit 10-21 ■ Impact of the Cost-Effectiveness Criterion on the Year-20 Backlog

Edition	Analysis Start Year	Cost Year	Annual Budget ($Billions)	Cost-Effectiveness Criterion	SGR Backlog		
					Year 0	Year 20	Change
23rd C&P	2014	2014	$11.295	Off	$98.0	$116.2	
				On	$98.0	$108.8	($7.4)
24th C&P	2016	2016	$11.610	Off	$105.1	$113.0	
				On	$105.1	$102.3	($10.7)

Source: Transit Economic Requirements Model.

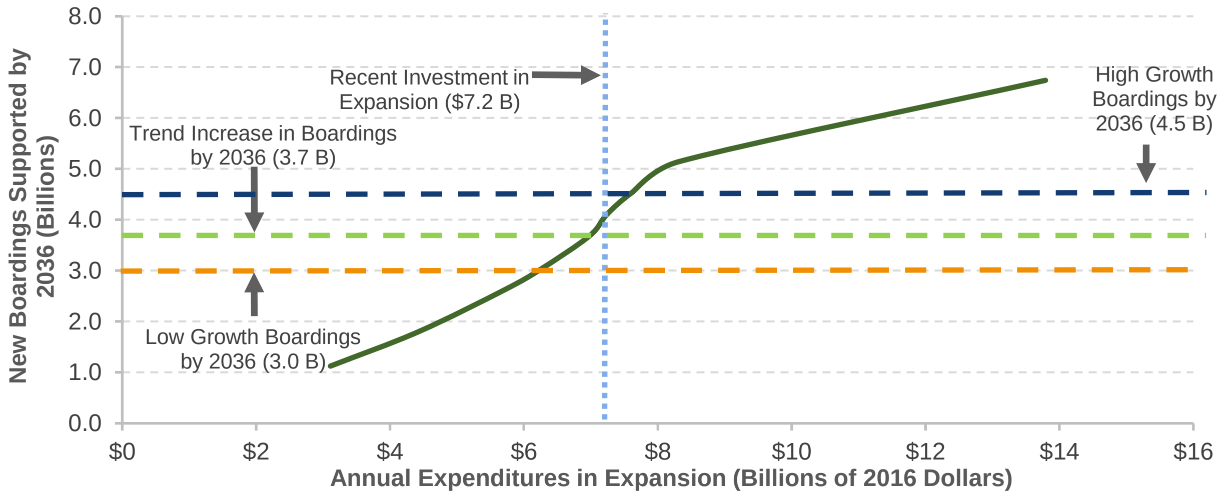
Impact of Expansion Investments on Transit Ridership

Although capital spending on preservation primarily benefits the physical condition of existing transit assets, expansion investments are typically undertaken to expand the asset base to accommodate projected growth in ridership and potentially to improve service performance for existing transit system users.

Exhibit 10-22 shows the relationship between aggregated annual capital spending by all levels of government on expansion investments and the additional number of annual passenger boardings that transit systems would be able to support by 2036. More precisely, this chart presents the level of expansion investment required to ensure that transit vehicle occupancy rates are maintained at current levels over the next two decades for a broad range of the potential rates of growth in transit passenger miles traveled. As the upward sloping curve of the chart indicates, higher levels of investment are required to support greater numbers of additional riders at a constant level of service. If investment levels are insufficient to support the projected growth in ridership fully, vehicle occupancy rates will tend to increase, leading to increased crowding on high-utilization systems and potentially leading to increased dwell times at stops, reduced average operating speeds, and increased rates of vehicle wear. Conversely, if the rate of transit capacity expansion exceeds the actual rate of ridership growth, occupancy rates will tend to decline, but cost-effectiveness (operating expenses per PMT) and other financial indicators will worsen, increasing the operating deficit, which might require fare increases and/or additional public funds.

The findings presented in *Exhibit 10-21* suggest the following trends. First, the recent rate of investment in asset expansion ($7.2 billion in 2016 dollars) could support roughly 4.1 billion additional boardings by 2036 (approximately a 1.7-percent annual growth in ridership). If the actual rate of future ridership growth is close to the trend rate of growth for the past 15 years, an average capital investment of $7.0 billion annually in transit expansion would be required over the next 20 years to support an additional 3.7 billion annual boardings—again after excluding expansion investments that do not pass TERM's benefit-cost test. Thus, the recent level of transit capital expansion investment is more than that required to support future rider growth, assuming future growth aligns with the 15-year historical trend. The result would be increased crowding on some bus and rail systems, increased rates of asset wear, and the potential for increased service delays due to crowding, dwell time increases, and breakdowns.

Exhibit 10-22 ■ New Ridership Supported in 2036 by Expansion Investments in All Urbanized and Rural Areas



Total New Boardings by 2036				
Average Annual Investment (Billions of 2016 Dollars)	**Average Annual Percent Change vs. Maintain Recent Spending**	**New Riders Supported (Billions of Annual Boardings)**	**Average Annual Growth in Boardings[1]**	**Funding Level Description**
$13.8	6.0%	6.7	2.5%	Highest Growth Scenario (+1.0%)
$8.3	1.4%	5.1	2.0%	Higher Growth Scenario (+0.5%)
$7.6	0.5%	4.5	1.8%	High Growth Scenario (+0.3%)
$7.2	0.0%	4.1	1.7%	Maintain Recent Spending
$7.0	-0.4%	3.7	1.5%	15 Year Historic Growth Rate Trend
$6.3	-1.5%	3.0	1.3%	Low Growth Scenario (-0.3%)
$5.7	-2.4%	2.6	1.1%	Lower Growth Scenario (-0.5%)
$4.4	-3.9%	1.8	0.8%	Lower Growth Scenario (-1.0%)
$3.1	-9.8%	1.1	0.5%	Lowest Growth Scenario (-1.5%)

[1] As compared with total urban ridership in 2016; only includes increases covered by investments passing TERM's benefit-cost test.

Note: TERM assesses expansion needs at the agency-mode level subject to (1) current vehicle occupancy rates at the agency-mode level and (2) expected transit PMT growth at the UZA level (hence, all agency modes within a given UZA are subject to the same transit PMT growth rate). However, TERM does not generate expansion needs estimates for agency modes that have occupancy rates that are well below the national average for that mode.

Source: Transit Economic Requirements Model.