# PART II: Investing for the Future

# Introduction

Chapters 7 through 10 present and analyze several possible scenarios for future capital investment in highways, bridges, and transit. In each of these 20-year scenarios, the investment level is an estimate of the spending that would be required to achieve a certain specified level of system performance. **This report does not attempt to address issues of cost responsibility**. The scenarios do not address how much different levels of government might contribute to funding the investment, nor do they address the potential contributions of different public or private revenue sources.

The four investment-related chapters in Part II measure investment levels in constant 2016 dollars, except where noted otherwise. The chapters consider scenarios for investment from 2017 through 2036 that are geared toward maintaining some indicator of physical condition or operational performance at its 2016 level, sustaining investment at recent levels, or achieving some objective linked to benefits vs. costs. The average annual investment level over the 20 years from 2017 through 2036 is presented for each analyzed scenario.

Chapter 7, **Capital Investment Scenarios**, defines the core scenarios and examines the associated projections for conditions and performance. It also explains how the projections are derived by supplementing the modeling results with assumptions about nonmodeled investment. The analyzed scenarios are intended to be illustrative and do not represent comprehensive alternative transportation policies; the U.S. Department of Transportation (DOT) does not endorse any scenario as a target level of investment.

Chapter 8, **Supplemental Analysis**, explores some implications of the scenarios presented in Chapter 7, and discusses potential alternative methodologies. It includes a comparison of highway projections from previous editions of the C&P Report with current findings. This edition includes a special section looking back at the 1968 Highway Needs report, in recognition of the 50th anniversary of the report series.

Chapter 9, **Sensitivity Analysis**, explores the impacts on scenario projections of changes to several key assumptions that are relatively arguable, such as the discount rate and the future rate of growth in travel demand.

Lastly, Chapter 10, **Impacts of Investment**, explores the impacts of alternative levels of possible future investment on various indicators of conditions and performance and explains the derivation of the scenario projections from results obtained with the models that have been developed over the years to support the C&P Report. These models have evolved over time to incorporate recent research, new data sources, and improved estimation techniques; their current versions are described in Appendices A (highways), B (bridges), and C (transit). Even collectively, however, their scope does not cover all capital investment in these types of surface transportation infrastructure.

The combination of engineering and economic analysis in this part of the C&P Report is consistent with the movement of transportation agencies toward asset and performance management, value engineering, and greater consideration of cost-effectiveness in decision-making.

# Capital Investment Scenarios

Within this report, the term "investment" refers to capital spending, which does not include spending on maintenance. This includes capital spending on the rehabilitation of pavement, bridge, and transit assets that may be described as "maintenance" in other contexts. Additional discussion of the distinction between capital and maintenance spending is contained in Chapter 2 of this report.

The projections for the 20-year capital investment scenarios shown in this report reflect complex technical analyses that attempt to predict the potential impacts of capital investment on the future conditions and performance of the transportation system. These scenarios are illustrative, and DOT does not endorse any of them as a target level of investment. Where practical, supplemental information is included to describe the impacts of other possible investment levels.

The system conditions and performance projections in this report's capital investment scenarios represent what **could** be achievable assuming a particular level of investment, rather than what **would** be achieved. The analytical models used to develop the projections assume that, when funding is constrained, the benefit-cost ratio (BCR) establishes the order of precedence among potential capital projects, with projects having higher BCRs selected first. In actual practice, the BCR generally omits some types of benefits and costs because of difficulties in quantifying them and valuing them monetarily, and these other benefits and costs can and do affect project selection. In addition, actual project selection can be guided by other considerations outside benefit-cost analysis (BCA).

## Highway and Bridge Investment Scenarios

Projections for future conditions and performance under alternative potential levels of investment in highways and bridges, combined, are presented as scenarios in Chapter 7, and developed from projections in Chapter 10 using separate models and techniques for highway preservation and capacity expansion, and for bridge preservation. Investments in bridge repair, rehabilitation, and replacement are modeled by the National Bridge Investment Analysis System (NBIAS); those in capacity expansion and the highway resurfacing and reconstruction component of system rehabilitation are modeled by the Highway Economic Requirements System (HERS).

Some elements of highway investment spending are modeled by neither HERS nor NBIAS. Due to data limitations, Chapter 7 factors these elements into the investment levels associated with each scenario using scaling procedures external to the models. Although the NBIAS database includes information on all bridges, the Highway Performance Monitoring System (HPMS) database, on which the HERS model relies, includes detailed information only on Federal-aid highways. Thus, to develop scenarios based on all roads, nonmodel-based estimates must be generated for roads functionally classified as rural minor collectors, rural local, or urban local. In addition, HERS lacks information that would be needed to model types of capital spending identified as "system enhancement" in Chapter 2. This includes targeted safety-focused projects (e.g., adding rumble strips).

Whereas Chapter 7 focuses on investment scenarios for all roads, Chapter 10 includes model-based projections for Federal-aid highways, the National Highway System, and the Interstate System separately.

### Sustain Recent Spending Scenario

Some earlier C&P Report editions included analyses showing the impacts of sustaining spending at base-year levels, but the 2008 C&P Report was the first to include a full-fledged scenario projecting the impact of sustaining investment at base-year levels in constant-dollar terms. This approach was retained in subsequent editions; most recently, the 23rd C&P Report included a "Sustain 2014 Spending" scenario. Although this scenario has proven useful in providing a frame of reference to readers, one issue with this approach was that spending levels in a single base year could be influenced by one-time events, and might not be representative of typical annual spending. This edition replaces this scenario with a Sustain Recent Spending scenario, based on average annual spending over 5 years (2012–2016) converted to base-year (2016) constant dollars. This approach is expected to smooth out annual variations and make the scenarios more consistent between editions of this report. (In addition, as discussed in Chapter 2, the 2016 highway spending data presented in this C&P Report were all estimated, as actual data were not available in time for inclusion. Basing the scenario on a range of years rather than a single year reduces the influence of these estimated data.)

*Exhibit II-1* presents the derivation of the annual investment level for the Sustain Recent Spending scenario. Using the National Highway Construction Cost Index (NHCCI) to convert spending from current dollars to constant 2016 dollars yields an average annual capital spending level from 2012 to 2016 of $106.9 billion. The Sustain Recent Spending scenario projects the potential impacts of sustaining capital spending at this level in constant-dollar terms over the 20-year period of 2017 through 2036.

*Exhibit II-1* also shows the portion of total capital spending that was directed toward Interstate highways, the National Highway System, and Federal-aid highways. This distribution varied significantly by year (for example, the share of capital spending directed toward Interstate highways was 19.5 percent in 2012 compared to 24.0 percent in 2014), illustrating the utility of smoothing out the analysis using a multiyear perspective.

**Exhibit II-1** ■ Derivation of Annual Investment Level for the Sustain Recent Spending Scenario, Highways

| Functional System | 2012 | 2013 | 2014 | 2015 | 2016 | 5-Year Average |
|---|---|---|---|---|---|---|
| **National Highway Construction Cost Index (2003 Quarter 1 = 1.0000)** | | | | | | |
| Four-quarter Average | 1.6016 | 1.6130 | 1.6816 | 1.6984 | 1.6606 | |
| **Highway Capital Spending, All Levels of Government (Billions of Dollars)** | | | | | | |
| Current Dollars | $105.3 | $98.7 | $105.4 | $109.3 | $112.9 | $106.3 |
| Constant 2016 Dollars[1] | $109.2 | $101.6 | $104.1 | $106.9 | $112.9 | $106.9 |
| **Highway Capital Spending, by System (Billions of Constant 2016 Dollars)** [2] | | | | | | |
| Interstate Highway System | $21.2 | $19.8 | $25.0 | $25.7 | $26.4 | $23.6 |
| National Highway System | $56.6 | $52.7 | $55.6 | $57.1 | $59.2 | $56.2 |
| Federal-aid Highways | $81.9 | $76.3 | $78.3 | $80.4 | $84.1 | $80.2 |
| All Roads | $109.2 | $101.6 | $104.1 | $106.9 | $112.9 | $106.9 |

[1] Spending was converted from current to 2016 constant dollars by taking the value for a given year, dividing by the index value for that year, and multiplying by the index value for 2016.

[2] Note: The distribution by system in 2013 was estimated based on 2012 data; the distribution by system in 2015 and 2016 was estimated based on 2014 data.

Sources: FHWA Bulletin: Highway Funding 2013–2016, Table HF-10B; Highway Statistics, various years, Tables HF-10A and PT-1.

## Maintain Conditions and Performance Scenario

The Maintain Conditions and Performance scenario also assumes that capital spending in constant-dollar terms remains flat between 2017 and 2036—not at the recent spending level, but instead at the level that would result in selected performance indicators having the same values in 2036 as in 2016. For this edition of the C&P Report, the HERS component of the scenario is defined as the lowest level of investment required at a minimum to maintain each of two performance indicators—average pavement roughness and average delay per vehicle mile traveled (VMT)—at their base-year level or better. For the NBIAS component, the benchmark performance indicator is the percentage of bridges that are in poor condition, weighted by deck area.

## Improve Conditions and Performance Scenario

The investment levels for the Improve Conditions and Performance scenario are estimates of what would be needed to exactly fund all cost-beneficial highway and bridge improvements. This scenario represents an "investment ceiling" above which further investment would not be cost-beneficial, even if available funding were unlimited. The portion of this funding that is directed toward pavement and bridge rehabilitation (as opposed to capacity expansion) is described as the State of Good Repair benchmark. Given the existence of a backlog of unmet capital investment needs, the investment pattern of this scenario is front loaded, with the highest investment levels in the earliest years.

**Implications of Capital Spending under the Improve Conditions and Performance Scenario for Non-capital Spending**

Maintenance and other-non capital spending are substantial, constituting roughly half of all highway expenditures (see Chapter 2, Exhibit 2-2). One important question about the Improve Conditions and Performance scenario is how increasing the capital investment level could affect future non-capital costs.

While the HERS model focuses on capital investments, in estimating the benefits of such investments it considers their impact on routine maintenance costs. In the HERS model, maintenance spending per mile is estimated based on pavement condition and strength, with maintenance costs rising as pavement condition declines. As such, increases in capital spending on rehabilitation projects generally reduce the need for future maintenance spending by improving pavement condition. Conversely, increases in spending on capacity expansion projects increase the number of lanes that need to be maintained and thus imply higher future maintenance costs, all other things being equal. Based on the mix of projects included in the Improve Conditions and Performance scenario for this report, HERS projects an overall decline in maintenance costs per mile of 27.4 percent. The NBIAS model similarly estimates lower maintenance costs as bridge condition improves; NBIAS does not simulate capacity expansion projects.

The increased capital investment under the Improve Conditions and Performance scenario would likely result in additional planning costs, as the volume and complexity of projects included would tend to be greater than what is currently reflected in long-term capital investment plans. It is however unclear whether such increased planning costs would be directly proportional to increased capital investment levels. Other non-capital costs, such as administration and highway patrol, are not captured in the HERS model, but do not necessarily vary strongly with changes in capital investment.

To the extent that increased spending under the Improve Conditions and Performance scenario were financed through the issuance of bonds, this would tend to increase future bond interest and bond redemption expenses.

## Types of Capital Spending Projected by HERS and NBIAS

The types of investments HERS and NBIAS evaluate can be related to the system of highway functional classification introduced in Chapter 1 and to the broad categories of capital improvements introduced in Chapter 2 (system rehabilitation, system expansion, and system enhancement). NBIAS relies on the NBI database, which covers bridges in all highway functional classes, and evaluates improvements that generally fall within the system rehabilitation category.

HERS evaluates pavement improvements—resurfacing or reconstruction—and highway widening; the types of improvements included in these categories roughly correspond to system rehabilitation and system expansion as described in Chapter 2. In estimating the per-mile costs of widening improvements, HERS considers the typical number of bridges and other structures that would need modification. Thus, the estimates from HERS are considered to represent system expansion costs for both highways and bridges. Coverage of the HERS analysis is limited, however, to Federal-aid highways, as the HPMS sample does not include data for rural minor collectors, rural local roads, or urban local roads.

The term "nonmodeled spending" refers in this report to spending on highway and bridge capital improvements that are not evaluated in HERS or NBIAS. Such spending is not included in the analyses presented in Chapter 10, but the capital investment scenarios presented in Chapter 7 are adjusted to account for them. Nonmodeled spending includes capital improvements on highway classes omitted from the HPMS sample and hence the HERS model.

### Capital Improvements Modeled in HERS and NBIAS vs. Capital Improvement Type Categories Presented in Chapter 2

*Exhibit 2-13* (see Chapter 2) provides a crosswalk between a series of specific capital improvement types for which data are routinely collected from the States and three major summary categories: system rehabilitation, system expansion, and system enhancement. The types of improvements covered by HERS and NBIAS are assumed to correspond with the system rehabilitation and system expansion categories. As in *Exhibit 2-13*, HERS splits spending on "reconstruction with added capacity" among these categories.

For some of the detailed categories in *Exhibit 2-13*, the assumed correspondence is close overall but not exact. In particular, the extent to which HERS covers construction of new roads and bridges is ambiguous. Although not directly modeled in HERS, such investments are often motivated by a desire to alleviate congestion on existing facilities in a corridor, and thus would be captured indirectly by the HERS analysis in the form of additional normal-cost or high-cost lanes. To the extent that investments in the "new construction" and "new bridge" improvement types identified in Chapter 2 are motivated by desires to encourage economic development or accomplish other goals aside from the reduction of congestion on the existing highway network, such investments would not be captured in the HERS analysis.

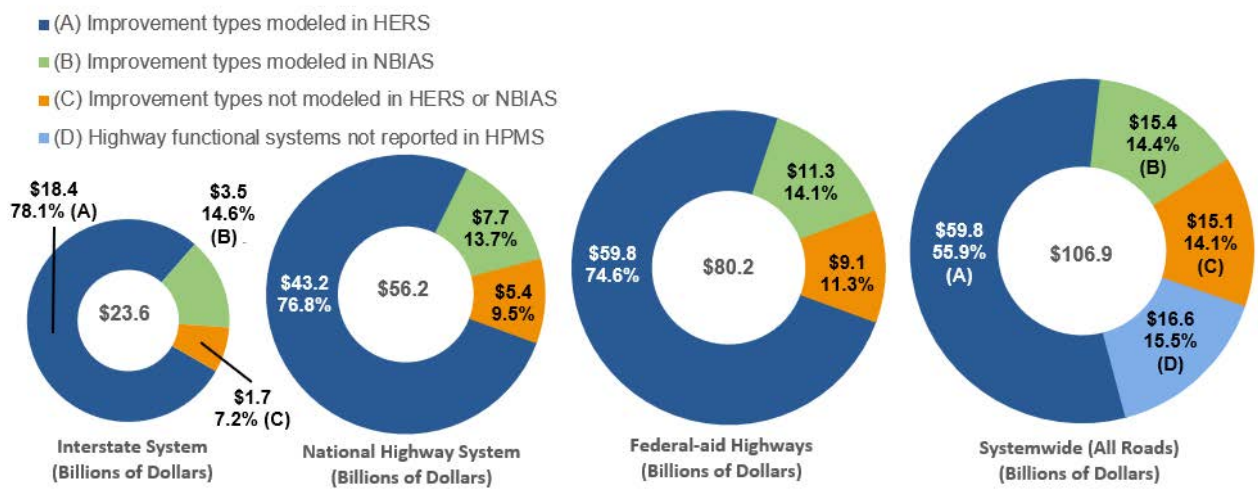
Some other comparability issues include:

- Some of the relocation expenditures identified in *Exhibit 2-13* may be motivated by considerations beyond those reflected in the curve and grade rating data that HERS uses in computing the benefits of horizontal and vertical realignments.
- The bridge expenditures that *Exhibit 2-13* counts as system rehabilitation could include work on bridge approaches and ancillary improvements that NBIAS does not model.
- HERS and NBIAS are assumed not to capture improvements that count as system enhancement spending, including the spending on the "safety" category in *Exhibit 2-12*. Some safety deficiencies, however, might be addressed as part of broader pavement and capacity improvements modeled in HERS.
- The HERS operations preprocessor described in Appendix A includes capital investments in operations equipment and technology that would fall under the definition of the "traffic management/engineering" improvement type in Chapter 2. These investments are counted among the nonmodeled system enhancements because they are not evaluated within the benefit-cost framework that HERS applies to system rehabilitation and expansion investments.

Nonmodeled spending also includes types of capital expenditures classified in Chapter 2 as system enhancements (safety enhancements, traffic operation improvements, and environmental enhancements), which neither HERS nor NBIAS currently evaluates. Although HERS incorporates assumptions about future operations investments, the capital components of which would be classified as system enhancements, the model does not directly evaluate the need for these deployments. In addition, HERS does not identify specific safety-oriented investment opportunities, but instead considers the ancillary safety impacts of capital investments that are directed primarily toward system rehabilitation or capacity expansion. (Part IV of this report references a recommendation to begin capturing Model Inventory of Roadway Elements [MIRE] data in the HPMS. The inclusion of such data would help facilitate direct analysis of safety-oriented investments within HERS in the future.)

*Exhibit II-2* shows that the systemwide highway capital spending for the Sustain Recent Spending scenario was $106.9 billion. (The Sustain Recent Spending scenario is discussed in greater detail in Chapter 7.) Of that spending, $59.8 billion (55.9 percent) was for the types of improvement that HERS models, and $15.4 billion (14.4 percent) was for the types of improvement NBIAS models. The other $31.7 billion, which was for nonmodeled highway capital spending, was divided between system enhancement expenditures and capital improvements to classes of highways not reported in HPMS.

**Exhibit II-2** ■ Distribution of Recent Capital Expenditures by Investment Type




Note: VMT is vehicle miles traveled; HERS is Highway Economic Requirements System; NBIAS is National Bridge Investment Analysis System.

Sources: Highway Statistics, various years (Table SF-12A), and unpublished FHWA data.

Because the HPMS sample data are available only for Federal-aid highways, the percentage of capital improvements classified as nonmodeled spending is lower for Federal-aid highways than is the case systemwide. Of the $80.2 billion in spending by all levels of government on capital improvements to Federal-aid highways in the Sustain Recent Spending scenario, 74.6 percent was within the scope of HERS, 14.1 percent was within the scope of NBIAS, and 11.3 percent was for spending not captured by either model. The percentage distribution differs somewhat for the Interstate System, with a higher share within the scope of HERS and NBIAS (78.1 percent and 14.6 percent, respectively) and a smaller share captured by neither (7.2 percent).

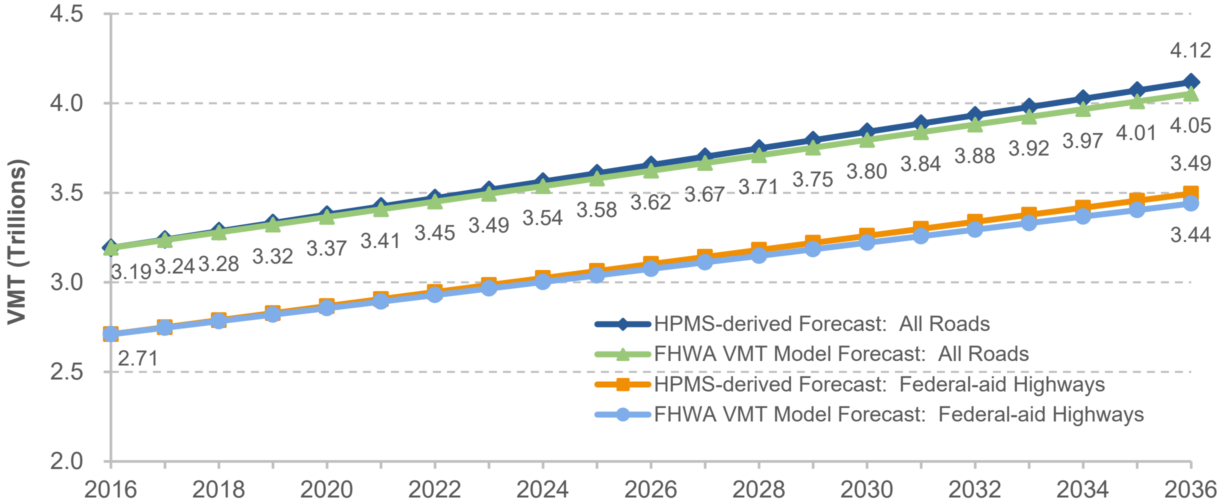
## Future Travel Volumes Assumed in HERS and NBIAS

As discussed in Chapter 9 (Traffic Growth Projections section), the HERS and NBIAS modeling in this edition of the C&P Report supplements section-level travel forecasts from the Highway Performance Monitoring System (HPMS) and bridge-level traffic forecasts from the National Bridge Inventory (NBI) with a 20-year national-level vehicle miles traveled (VMT) forecast from an FHWA econometric model. Aggregating the forecasts for individual sample sections yields a composite, weighted average annual travel growth rate of 1.28 percent. (Aggregating the traffic forecasts for individual bridges yields an average of 1.35 percent per year.) These location-specific forecasts were scaled down proportionally so that the national average would match the 1.2-percent value published online as *FHWA Forecasts of Vehicle Miles Traveled (VMT): Spring 2018*.

*Exhibit II-3* translates the HPMS-derived VMT growth rate and the FHWA VMT model forecast into projected VMT for each year from 2016 to 2036. Although the HPMS-derived forecast applies only to Federal-aid highways (the HPMS sample is limited to Federal-aid highways), this growth rate is applied to all VMT for illustrative purposes. A 1.2-percent annual FHWA VMT growth rate implies that national VMT will rise from 3.19 trillion in 2016 to 4.05 trillion in 2036, with VMT on Federal-aid highways rising from 2.71 trillion to 3.44 trillion over this period. Applying the 1.28-percent HPMS-derived forecast annual growth rate would yield national VMT of 4.12 trillion, of which 3.49 trillion would be on Federal-aid highways.

Consistent with the approach used in the last several C&P Reports, future VMT is assumed to grow linearly (so that one-twentieth of the additional VMT is added each year), rather than geometrically (growing at a constant annual rate). With linear growth, the annual percentage rate of growth gradually declines over the forecast period. This approach is logically consistent with the FHWA national VMT forecasting model, which projects lower average annual VMT growth rates over 30 years than it does over 20 years.

**Exhibit II-3** ■ Annual Projected Highway VMT Based on HPMS-derived Forecasts or FHWA VMT Forecast Model, 2016–2036




Note: VMT is vehicle miles traveled; HPMS is Highway Performance Monitoring System. Year-by-year values are shown only for the "FHWA VMT Model Forecast: All Roads" line, as these would be most appropriate for citation as FHWA's official forecast.

Sources: Highway Performance Monitoring System; FHWA Forecasts of Vehicle Miles Traveled, May 2018.

## Highway Economic Requirements System

Simulations conducted with HERS provide the basis for this report's analysis of investment in highway resurfacing and reconstruction and for highway and bridge capacity expansion. HERS uses incremental benefit-cost analysis to evaluate highway improvements based on data from HPMS. HPMS includes State-supplied information on current roadway characteristics, conditions, performance, and anticipated future travel growth for a nationwide sample of roughly 130,000 highway sections. HERS analyzes individual sample sections only as a step toward providing results at the national level; the model does not provide definitive improvement recommendations for individual sections.

The frame for which sections are sampled is the TOPS (Table of Potential Samples), in which each section is relatively homogeneous over its length with respect to traffic volume, geometrics, cross-section, and condition. For each State, the sampling is designed to enable statistically reliable estimation for each urbanized area, and at the statewide level for rural and for small urban areas. For each of these geographic categories, stratified random samples are drawn by traffic volume group. (The sampling methodology is further detailed in the HPMS Field Manual (https://www.fhwa.dot.gov/policyinformation/hpms/fieldmanual/).)

HERS simulations begin with evaluations of the current state of the highway system using data from the HPMS sample. These data provide information on pavements, roadway geometry, traffic volume and composition (percentage of trucks), and other characteristics of the sampled highway sections. For sections with one or more identified deficiencies, the model then considers potential improvements, including resurfacing, reconstruction, alignment improvements, and widening or adding travel lanes. HERS selects the improvement (or combination of improvements) with the greatest net benefits, with benefits defined as reductions in direct highway user costs, agency costs for road maintenance, and societal costs from vehicle emissions of pollutants. The model allocates investment funding only to those sections for which at least one potential improvement is projected to produce benefits exceeding construction costs.

HERS normally considers highway conditions and performance over a period of 20 years from the base ("current") year—the most recent year for which HPMS data are available. This analysis period is divided into four equal funding periods. After analyzing the first funding period, HERS updates the database to reflect the projected outcomes of the first period, including the effects of the selected highway improvements. The updated database is then used to analyze conditions and performance in the second period, the database is updated again, and so on through the fourth and final period.

The HERS model relies on a variety of assumptions about travel behavior and associated travel costs as well as the benefits and costs of infrastructure improvements. Research is conducted on an ongoing basis to assess the accuracy of these assumptions and, when possible, the HERS model assumptions are adjusted to reflect real-world dynamics more accurately. See Appendix A for a discussion of recent and ongoing enhancements to the model.

### Operations Strategies

HERS considers the impacts of certain types of highway operational improvements that feature intelligent transportation systems.[23] The operations strategies HERS currently evaluates are:

- Arterial management: upgraded signal control, electronic roadway monitoring, emergency vehicle signal preemption, variable message signs.
- Freeway management: ramp metering, electronic roadway monitoring, variable message signs, integrated corridor management, active traffic management (dynamic lane and merge controls, dynamic speed limits, queue warning systems).
- Incident management: detection, verification, response.
- Traveler information: 511 systems, advanced in-vehicle navigation systems with real-time traveler information.

It is important to note that HERS does not analyze the benefits and costs of these investments. Instead, a separate preprocessor predicts where such investments would most likely occur and estimates the impacts of these operations strategies on the performance of highway sections where they would be deployed. The resulting output is entered into HERS as the starting point for its analysis of pavement improvements and widening options. Due to the nature of this two-step process, HERS does not directly analyze tradeoffs between these types of operational improvements and potential widening options.

The analyses presented in this edition assume that the deployment of operational improvements over the next 20 years will continue at a rate consistent with existing patterns. HERS is also equipped to analyze the impact of a more aggressive deployment strategy over 20 years or over 5 years. The 2013 C&P report and 2015 C&P report included sensitivity analyses exploring the impacts of these alternatives.

## Travel Demand Elasticity

A key feature of the HERS economic analysis is the influence of the cost of travel on demand for travel. HERS represents this relationship as a travel demand elasticity that relates demand, measured by VMT, to changes in the average user cost of travel. Such changes could result from either:

- Changes in highway conditions and performance as measured by travel delay, pavement condition, and crash costs, relative to base year levels. The elasticity mechanism reduces travel demand when these changes are for the worse (e.g., travel delay increases) and increases travel demand when changes are for the better (e.g., pavement condition improves); or

[23] https://www.pcb.its.dot.gov/eprimer/default.aspx

- Deviations from the presumed user cost of travel built into the baseline demand forecasts (e.g., changes in fuel prices not considered in the forecasts).

HERS also allows the induced demand predicted through the elasticity mechanism to influence the cost of travel to highway users. For example, a 10-percent reduction in travel cost per mile would be predicted to induce a 6-percent increase in VMT in the short term, and a larger increase—just under 12 percent—5 years later, as travelers are able to make additional responses to the change in costs. On congested highway sections, the initial relief afforded by an increase in capacity will reduce the average user cost per VMT, which in turn will stimulate demand for travel; this increased demand will in turn offset some of the initial congestion relief. The elasticity feature operates likewise with respect to improvements in pavement quality by allowing for induced traffic that adds to pavement wear. This feature works in both directions: if the conditions and performance of a highway section worsen relative to base year conditions, a portion of projected future travel on that section would be suppressed.

One implication of the inclusion of travel demand elasticity in HERS is that the overall projected level of future VMT is directly affected by the assumed level of future highway capital spending. Simulations with relatively higher investment levels that lead to reductions in average user costs will project higher future traffic volumes than will simulations with relatively lower investment levels that lead to increases in average user costs. The annual projected VMT values identified in *Exhibit II-3* represent inputs to this process, and typically would not match the outputs from this process.

## National Bridge Investment Analysis System

The scenario estimates specific to bridge repair and replacement discussed in this edition of the C&P Report are derived primarily from NBIAS. NBIAS can synthesize element-level data from the general condition ratings reported for individual bridges in the NBI. The analyses are based on synthesized element-level data. Examples of bridge elements include bridge decks, steel girders used for supporting the deck, concrete pier caps on which girders are placed, concrete columns used for supporting the pier cap, and bridge railings. Bridge elements are discussed in greater detail in Chapter 6 and Appendix B.

NBIAS uses a probabilistic approach to model bridge deterioration for each synthesized bridge element. It relies on a set of transition probabilities to project the likelihood that an element will deteriorate from one condition state to another over a given period. This information, along with details on the cost of maintenance, repair, and rehabilitation (MR&R) actions, is used to predict life-cycle costs of maintaining existing bridges, and to develop MR&R policies specifying what MR&R action to perform based on the existing condition of a bridge element. Under this analysis, replacement of a bridge is recommended if a bridge evaluation results in lower life-cycle costs compared with the recommended MR&R work. (Notwithstanding the use of the term "maintenance," the MR&R actions considered in NBIAS are actually capital improvements; preventive maintenance, such as cleaning scuppers or washing bridges, is not modeled.)

To estimate functional improvement needs, NBIAS applies a set of improvement standards and costs to each bridge in the NBI. The system then identifies potential improvements—such as widening existing bridge lanes, raising bridges to increase vertical clearances, and strengthening bridges to increase load-carrying capacity—and evaluates their potential benefits and costs. NBIAS evaluates potential bridge replacements by comparing their benefits and costs with what could be achieved through MR&R work alone. Appendix B discusses NBIAS in detail.

# Transit Investment Scenarios

The transit investment analyses presented in this report are based on results from the Transit Economics Requirements Model (TERM). The transit section of Chapter 10 evaluates the impact of varying levels of capital investment on various measures of conditions and performance, whereas the transit section of Chapter 7 provides a more in-depth analysis of specific investment scenarios.

TERM includes a benefit-cost test that is applied to expansion scenarios to determine which investments are cost-effective and which are not. For scenarios in which this test is enabled, TERM reports investment costs only for investments that pass the test.

The Sustain Recent Spending scenario projects the potential impacts of sustaining preservation and expansion spending at recent spending levels, based on average annual spending over 5 years (2012–2016) converted to base-year (2016) constant dollars. *Exhibit II-4* presents the derivation of the annual investment level for this scenario. Using the RS Means Construction Index to convert spending from current dollars to constant 2016 dollars yields an average annual capital spending level from 2012 to 2016 of $18.9 billion. The Sustain Recent Spending scenario projects the potential impacts of sustaining capital spending at this level in constant-dollar terms over the 20-year period of 2017 through 2036. The scenario applies BCA to prioritize investments within this constrained budget target.

### **Exhibit II-4** ■ Derivation of the Annual Investment Level for the Sustain Recent Spending Scenario, Transit

| Functional System | 2012 | 2013 | 2014 | 2015 | 2016 | 5-Year Average |
|---|---|---|---|---|---|---|
| **RS Means Construction Index (2016 = 100)** | | | | | | |
| Four-quarter Average | 92.73 | 94.37 | 97.58 | 99.37 | 100.00 | |
| **Transit Capital Spending, All Modes (Billions of Dollars)** | | | | | | |
| Current Dollars | $16.8 | $17.1 | $17.4 | $19.3 | $19.4 | $18.0 |
| Constant 2016 Dollars | $18.4 | $18.4 | $18.1 | $19.7 | $19.4 | $18.9 |
| **Annual Transit Capital Expenditures, by Purpose (Billions of Constant 2016 Dollars)** | | | | | | |
| Preservation | $10.7 | $11.7 | $11.6 | $12.6 | $12.7 | $11.6 |
| Expansion | $7.7 | $6.8 | $6.6 | $7.0 | $6.7 | $7.2 |

Note: Excludes reduced reporter agencies.
Source: National Transit Database.

The State of Good Repair benchmark projects the level of investment needed to bring all assets to a state of good repair over the next 20 years, defined as asset condition ratings of 2.5 or higher on a 5-point scale (Chapter 6 discusses these ratings). This benchmark assumes no future ridership growth, focusing solely on the preservation of existing assets, and does not apply the TERM benefit-cost test. The SGR Benchmark estimates the cost of maintaining what is currently in service as an analytical exercise.

The Low-Growth and High-Growth scenarios each add a system expansion component to the system preservation needs associated with the State of Good Repair benchmark. The goal of these scenarios is to preserve existing assets and to expand the transit asset base to support projected ridership growth over 20 years, based on forecasts linked to the average annual growth experienced between 2001 and 2016. The Low-Growth scenario projects ridership growth at 0.3 percent per year below the historical trend (over 15 years), whereas the High-Growth scenario incorporates a more extensive expansion of the existing transit asset base to support ridership growth at 0.3 percent per year above the historical trend. The resulting ridership rate in the Low-Growth scenario is 1.28 percent per year. Both scenarios incorporate a benefit-cost test for evaluating potential investments; thus, their system preservation components are somewhat smaller than the level identified in the State of Good Repair benchmark.

The data used to support TERM's needs estimates are derived from a variety of sources—including fleet investment and transit performance data obtained from the National Transit Database (NTD), asset inventory data provided by local transit agencies (at FTA's request), and historical annual rates of ridership growth calculated by region, agency size, and mode. The rate used in the Low-Growth scenario decreases the 15-year historical growth rate for all modes by 0.3 percent without allowing any growth rates to go below zero. The resulting ridership rate in the Low-Growth scenario is 1.28 percent per year. The rate in the High-Growth scenario is 1.82 percent per year. Appendix C contains a detailed description of the analysis methodology used by TERM, and Chapter 8 provides additional detail on the growth rates.

## Transit Economic Requirements Model

TERM is an analysis tool that uses algorithms based on engineering and economic concepts to forecast total capital investment needs for the U.S. transit industry through a 20-year time horizon. Specifically, TERM is designed to forecast the following types of investment needs:

- Preservation: The level of investment in the rehabilitation and replacement of existing transit capital assets required to attain specific investment goals (e.g., to attain a State of Good Repair [SGR]) subject to potentially limited capital funding.
- Expansion: The level of investment in the expansion of transit fleets, facilities, and rail networks required to support projected growth in transit demand (i.e., to maintain performance at current levels as demand for service increases).

The data used to support TERM's needs estimates are derived from a variety of sources—including fleet investment and transit performance data obtained from the National Transit Database (NTD), asset inventory data provided by local transit agencies (at FTA's request), and historical annual rates of ridership growth calculated by region, agency size, and mode. Appendix C contains a detailed description of the analysis methodology used by TERM, and Chapter 8 provides additional detail on the growth rates.

### Preservation Investments

TERM estimates current and future preservation investment needs by first assessing the current condition of the Nation's existing stock of transit assets. (The results of this analysis were presented in Chapter 6 of this report.) TERM then uses this information to assess both current reinvestment needs (i.e., the reinvestment backlog) and the expected level of ongoing investment required to meet the life-cycle needs of the Nation's transit assets over the next 20 years, including all required rehabilitation and replacement activities.

#### *Condition-based Reinvestment*

Rather than relying on age alone in assessing the timing and cost of current and future reinvestment activities, TERM uses a set of empirical asset deterioration curves that estimate asset condition (both current and future) as a function of asset type, age, past rehabilitation activities, and, depending on asset type, past maintenance and utilization levels. An asset's estimated condition at the start of each year over the 20-year forecast horizon determines the timing of specific rehabilitation and replacement activities. Asset condition declines as an asset ages, triggering reinvestment events at different levels of deterioration and ultimately leading to outright replacement.

#### *Financial Constraints, the Investment Backlog, and Future Conditions*

TERM is designed to estimate investment needs with or without annual capital funding constraints. When run without funding constraints, TERM estimates the total level of investment required to complete all rehabilitation and replacement needs the model identifies at the time those investment needs come due (hence, with unconstrained analyses after any initial deferred investment is addressed, investment backlog is not appreciable in subsequent years). In contrast, when TERM is run in a financially constrained mode, sufficient funding might not be available to cover the reinvestment needs of all assets. In this case, some reinvestment activities would be deferred until sufficient funds become available. The lack of funds to address all reinvestment needs for some or all of the 20 years of the model forecast results in varying levels of investment backlog during this period. Most analyses presented in this chapter were completed using funding constraints. Similarly, TERM's ability to estimate asset conditions—both current and future—allows for assessment of how future asset conditions are likely to improve or decline given varying levels of capital reinvestment. Finally, note that TERM's benefit-cost analysis is used to determine the order in which reinvestment activities are completed when funding capacity is limited, with investments having the highest benefit-cost ratios addressed first.

### Expansion Investments

In addition to ongoing reinvestment in existing assets, most transit agencies invest in the expansion of their vehicle fleets, maintenance facilities, fixed guideway, and other assets. Investments in expansion assets can be considered as serving two distinct purposes. First, the demand for transit services typically increases over time in line with population growth, employment, and other factors. To maintain current levels of performance in the face of expanding demand, transit operators must similarly expand the capacity of their services (e.g., by increasing the number of vehicles in their fleets). Failure to accommodate this demand would result in increased vehicle crowding, increased dwell times at passenger stops, and decreased operating speeds for existing services. Second, transit operators also invest in expansion projects with the aim of improving current service performance. Such improvements include capital expansion projects (e.g., a new light rail segment) to reduce vehicle crowding or increase average operating speeds. TERM is designed to assess investment needs and impacts for both types of expansion investments.

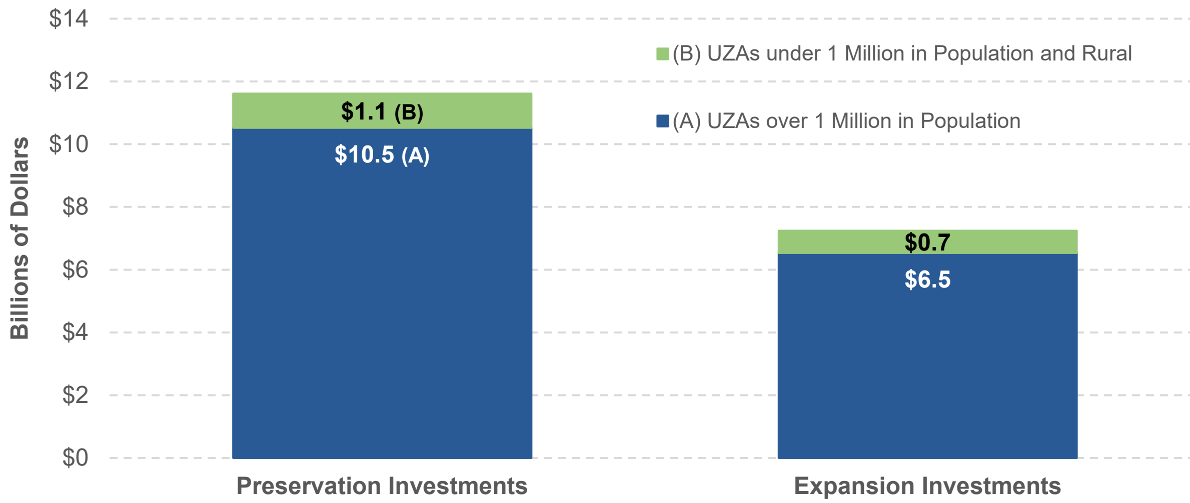
To assess the level of investment required to maintain existing service quality, TERM estimates the rate of growth in transit vehicle fleets required to maintain current vehicle occupancy levels given the projected growth rate in transit passenger miles. In addition to assessing the level of investment in new fleet vehicles required to support this growth, TERM forecasts investments in the expansion of other assets needed to support projected fleet growth, including bus maintenance facilities and—in the case of rail systems—additional investment in guideway, track work, stations, maintenance facilities, train control, and traction power systems. Asset expansion investment needs are assessed on a mode-by-mode basis for all agencies reporting to NTD. Cost-benefit constraints, however, prevent TERM from investing in asset expansion for those agency modes having lower ridership (per vehicle) than the national average.

## Recent Investment in Transit Preservation and Expansion

*Exhibit II-5* shows the broad composition of average annual capital expenditures by U.S. transit agencies over the period 2010–2016. Of the total spending of $18.9 billion, $11.6 billion or 61.6 percent was devoted to preserving existing assets, and the rest was spent on expansion investments.

As expected, preservation and expansion spending were concentrated in the large urban systems. Urbanized areas with populations greater than 1 million accounted for an average of 90.6 percent of preservation spending and 90.2 percent of expansion spending. Smaller urbanized and rural areas accounted for the rest. Although preservation and expansion spending for rural systems is small relative to that for large urban systems, rural transit service has been growing at roughly 2 percent annually since 2008. Every State and four U.S. Territories provide some form of rural transit service in low-density areas, improving the accessibility for Americans living in these areas.

**Exhibit II-5** ■ Recent Transit Capital Expenditures (Average 2012–2016)




Source: National Transit Database.

## Comparisons Between Report Editions

The base year of the analysis typically advances 2 years between successive editions of this biennial report. During this period, changes in many real-world factors can affect the investment scenario estimates. Among these factors are construction costs and other prices, conditions and performance of the highway and transit systems, expansion of the system asset base, and changes in technology (such as improvements in motor vehicle fuel economy). Although relevant to all scenarios, the implications of these changes are particularly significant for scenarios aimed at maintaining base-year conditions. Comparability across C&P Report editions is also limited by changes over time in analytical tools, data sets used in generating the scenarios, and scenario definitions.

### Choice of 5-year Period for Sustain Recent Spending Scenario

The shift from a Sustain Current (1-year) Spending scenario to a Sustain Recent (5-year) Spending scenario was driven by a desire to smooth out the effects that one-time events could have on spending patterns in a particular year. This report often looks back 10 years in documenting conditions, performance, and funding trends, but this period was considered too long to be representative of typical recent spending. Although shorter periods, such as 3 years, were considered, a 5-year period was ultimately selected based on an examination of historical annual spending patterns.

Although the 5-year (2012–2016) average annual highway capital spending level of $106.9 billion is higher in constant-dollar terms than the $112.9 billion estimated for 2016 alone, this is not always the case for 5-year averages vs. single-year values. For example, had a Sustain Recent Spending scenario been presented in the 23rd C&P Report, it would have had a higher annual funding level than the Sustain 2014 Spending scenario that was presented, as the 5-year average from 2010 to 2014 was higher in constant-dollar terms than highway capital spending in 2014 alone.

Similarly, although the 5-year (2012–2016) average annual transit capital spending level of $19.5 billion is higher in constant-dollar terms than the $18.5 billion spent in 2016 alone, the gap would be much smaller if comparing the average from 2010–2014 with 2014 spending.

# Modeling Considerations

Applying an economic approach to transportation investment modeling entails analysis and comparison of benefits and costs. Investments that yield benefits for which the values exceed their costs increase societal welfare and are thus considered "economically efficient," or "cost-beneficial." Although the 1968 National Highway Needs Report to Congress began as a mere "wish list" of State highway needs, the approach to estimating investment needs in the C&P Report has become more economically focused and in other ways more sophisticated over time. The HERS model was first utilized in the production of the 1995 C&P Report. TERM was introduced in the 1997 C&P report, whereas NBIAS was first used in the 2002 C&P report. Each of these tools has subsequently undergone several rounds of updates and refinements to expand their accuracy and coverage. Appendix D describes an ongoing *Reimagining the C&P Report in a Performance Management-Based World* effort initiated by the Federal Highway Administration in late 2012, which includes an evaluation of alternative methodologies to replace or improve the BCA-driven tools currently used in the C&P Report.

As in any modeling process, simplifying assumptions have been adopted to make analysis practical and to report within the limitations of available data. Because asset owners at the State and local levels primarily make the ultimate decisions concerning highways, bridges, and transit systems, they have a more direct need to collect and retain detailed data on individual system components. The Federal government collects selected data from States and transit operators to support this report and several other Federal activities, but these data are not sufficiently robust to make definitive recommendations concerning specific transportation investments in specific locations.

Each of the models used in this report—HERS, NBIAS, and TERM—omits various types of investment impacts from its BCAs. To some extent, these omissions reflect the national coverage of the models' primary databases. Although consistent with this report's focus on the Nation's highways and transit systems, such broad geographic coverage requires some sacrifice of detail to stay within feasible budgets for data collection. In the future, technological progress in data collection and growing demand for data for performance management systems for transportation infrastructure likely will yield national databases that are more comprehensive and of better quality.

HERS, NBIAS, and TERM have not yet evolved to the point that they can be used for direct multimodal analysis. Although the three models use BCA, their methods for implementing this analysis are very different. Each model is based on a separate, distinct database. Each model uses data applicable to its specific part of the transportation system and addresses issues unique to each mode. For example, HERS assumes that adding lanes to a highway causes highway user costs to decline, which results in additional highway travel. Under this assumption, some of this increased traffic would be newly generated travel and some could be the result of travel shifting from transit to highways. HERS, however, does not distinguish between different sources of additional highway travel. Similarly, TERM's BCA approach assumes that some travel shifts from automobile to transit because of transit investments, but the model cannot project the effect of such investments on highways.

## Uncertainty in Transportation Investment Modeling

The three investment analysis models used in this report are deterministic, not probabilistic, in that they provide a single projected value of total investment for a given scenario rather than a range of likely values. As a result, only general statements can be made about the element of uncertainty in these projections, based on the characteristics of the process used to develop them; specific information about confidence intervals cannot be developed. As was indicated earlier in this section, the analysis in Chapter 9 of this edition of the C&P Report enables uncertainty to be addressed by exploring the sensitivity of the scenario projections to changes in the underlying parameters (e.g., discount rates, value of time saved, statistical value of lives saved). As much as is possible, the range of variation considered in these tests corresponds to the range considered plausible in the corresponding research literature or to ranges recommended in authoritative guidance. The sensitivity tests address only some of the elements of uncertainty in the scenario projections. In some cases, the uncertainty extends beyond the value of a model parameter to the entire specification of the equations in which the parameters are embedded.

Future travel projections are central to evaluating capital investment on transportation infrastructure. Forecasting future travel, however, is extremely difficult because of the many uncertainties related to traveler behavior. Even where the underlying relationships may be correctly modeled, the evolution of key variables (such as expected regional economic growth) could differ significantly from the assumptions made in the travel forecast. Future transit ridership projections have significant implications for estimated system expansion needs, but there is uncertainty regarding long-term growth rates, particularly in light of recent declines in transit ridership. Neither the transit nor highway travel forecasts reflect the potential impacts of emerging transportation technology options such as car share, scooters, and autonomous vehicles.