part II

Investment/Performance Analysis

Introduction

To support the development and evaluation of transportation policies and programs, Chapters 7 through 10 present and analyze general 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 level of infrastructure performance. **The scenarios do not address how much different levels of government might contribute to funding the investment, nor do they directly address the potential contributions of different public or private revenue sources**.

The four investment-related chapters in Part II measure investment levels in constant 2012 dollars, except where noted otherwise, and include the following analyses:

Chapter 7, **Potential Capital Investment Impacts**, analyzes the projected impacts of alternative levels of future investment on measures of physical condition, operational performance, and benefits to system users. Each alternative pertains to investment from 2013 through 2032 and is presented as an annual average level of investment and as the constant annual percentage rate of increase or decrease in investment that would produce that annual average.

Chapter 8, **Selected Capital Investment Scenarios**, examines several scenarios distilled from the investment alternatives considered in Chapter 7. Some of the scenarios are oriented around maintaining different aspects of system condition and performance or achieving a specified minimum level of performance, while others link to broader measures of system user benefits. The scenarios included in this chapter 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 9, **Supplemental Scenario Analysis**, explores some of the implications of the scenarios presented in Chapter 8 and contains some additional policy-oriented analyses addressing issues not covered in Chapters 7 and 8. As part of this analysis, highway projections from previous editions of the C&P report are compared with actual outcomes to elucidate the value and limitations of the projections presented in this edition.

Chapter 10, **Sensitivity Analysis**, explores the impacts on scenario projections by varying some of the key assumptions. The investment scenario projections in this report are developed using models that evaluate current system condition and operational performance and make 20-year projections based on assumptions about future travel growth and a variety of engineering and economic variables. The accuracy of these projections depends, in large part, on the realism of these assumptions. Since the future rate of growth in transit travel is uncertain, Chapter 7 considers alternative high and low values for this parameter. Chapter 10 likewise varies the assumed rate of growth in highway travel and the values assumed for the discount rate, the value

of travel time savings, and other assumed parameters. Other sources of uncertainty in the modeling procedures are discussed below.

Unlike Chapters 1 through 6, which largely present highway and transit statistics drawn from other sources, the investment scenario projections presented in these chapters (and the models used to create the projections) were developed exclusively for the C&P report. The procedures for developing the investment scenario estimates have evolved over time to incorporate recent research, new data sources, and improved estimation techniques. These procedures are described more fully in Appendices A (Highways), B (Bridges), and C (Transit).

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. The economic approach to transportation investment is discussed at the end of this section.

Capital Investment Scenarios

The projections for the 20-year capital investment scenarios shown in this report reflect complex technical analyses that attempt to predict the impact that capital investment might have 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.

This report does not attempt to address issues of cost responsibility. The investment scenarios predict the impact that particular levels of combined Federal, State, local, and private investment might have on the overall conditions and performance of highways, bridges, and transit. Although Chapter 6 provides information on what portion of highway investment has come from different levels of government in the past, the report makes no specific recommendations about what these portions, or that from the private sector, should be in the future.

State Use of Benefit-Cost Analysis

DOT recently issued a report to Congress, *Use of Benefit-Cost Analysis by State Departments of Transportation*, in response to a requirement in Senate Report 113-182 accompanying the Transportation and Housing and Urban Development, and Related Agencies Appropriations Bill, 2015.

The study revealed that the extent to which State DOTs use benefit-cost analysis continues to vary significantly among States, project types, and planning stages. The quality of benefit-cost analysis also varies, as it is affected by availability of data and appropriate baselines for comparison, benefit definitions, and accuracy of traffic demand forecasts. State DOTs face institutional, resource, and technical challenges in conducting benefit-cost analysis. Potential strategies to address these challenges include outreach and communication, technical training, and provision of assistance in methodological issues.

The system condition 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 models used to develop the projections generally 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 valuing them monetarily, and these other benefits and costs can and do affect project selection. In addition, actual project selection can be guided by political or other considerations outside benefit-cost analysis.

Highway and Bridge Investment Scenarios

Projections for future conditions and performance under alternative potential levels of investment are developed independently for highways and bridges in Chapter 7 using separate models and techniques, and then combined for selected investment scenarios in Chapter 8. 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). Although HERS was primarily designed to analyze highway segments, it also factors in the costs of expanding bridges and other structures when determining whether to add lanes to a highway segment. Some elements of highway investment spending are modeled by neither HERS nor NBIAS. Chapter 8 factors these elements into the investment levels associated with each scenario using scaling procedures external to the models. The scenario investment levels are estimates of the amount of future capital spending required to meet the performance goals specified in the scenarios.

Chapter 8 uses consistent performance criteria to create separate but parallel investment scenarios for all Federal-aid highways, the National Highway System, and the Interstate System. Corresponding scenarios are also presented for all roads system wide, but projections for these scenarios are less reliable because data coverage is more limited off the Federal-aid highways. 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; for the scenarios based on all roads, non-model-based estimates must be generated for roads functionally classified as rural minor collectors, rural local, or urban local.

The **Sustain 2012 Spending scenario** projects the potential impacts of sustaining capital spending at 2012 base-year levels in constant-dollar terms over the 20-year period 2013 through 2032. The **Maintain Conditions and Performance scenario** assumes that combined highway capital investment by all levels of government gradually changes in constant-dollar terms over 20 years to the point at which selected performance indicators in 2032 are maintained at their 2012 base-year levels. For this edition of the C&P report, the HERS component of the scenario is defined as the lowest level of investments required to at least 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 deck area on deficient bridges.

The investment levels for the **Improve Conditions and Performance scenario** are determined by identifying the highest rate of annual spending growth for which potentially cost-beneficial highway and bridge improvements can be identified. 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 scenario directed toward addressing engineering deficiencies on pavements and bridges is described as the **State of Good Repair benchmark**.

Transit Investment Scenarios

The transit section of Chapter 7 evaluates the impact of varying levels of capital investment on various measures of condition and performance, while the transit section of Chapter 8 provides a more in-depth analysis of specific investment scenarios.

The **Sustain 2012 Spending scenario** projects the potential impacts of sustaining preservation and expansion spending at 2012 base-year levels in constant-dollar terms over the 20-year period of 2013 through 2032. The scenario applies benefit-cost analysis to prioritize investments within this constrained budget target.

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 3 discusses these ratings). This scenario does not apply a benefit-cost test and focuses solely on the preservation of existing assets.

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 expand the transit asset base to support projected ridership growth over 20 years based on forecasts linked to the average annual growth experienced between 1997 and 2012. The Low-Growth scenario projects ridership growth at 0.5 percent per year less than the historic trend, while the High-Growth scenario incorporates a more extensive expansion of the existing transit asset base to support ridership growth at 0.5 percent per year above the historic trend. 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.

Comparisons between Report Editions

When comparing capital investment scenarios presented in different editions of the C&P report, several considerations should be taken into account.

Scenario definitions have been modified over time. Between the 2013 C&P Report and the current edition, the target performance indicators in the **Maintain Conditions and Performance scenarios** have changed. In the 2013 edition, the indicator for investments modeled by HERS was the average between the investment levels required to maintain, alternatively, average pavement roughness or average congestion delay per VMT. For the investments modeled by NBIAS, the target performance indicator in the 2013 edition was the average sufficiency rating for bridges.

Before the 2013 edition, the scenarios in the C&P report for highway and bridge investment assumed that VMT would grow as forecast by the States for HPMS. The 2013 edition added an alternative set of scenarios that projected aggregate growth in VMT at the 15-year historic trend rate. This change made the highway and bridge investment scenarios more comparable to the

transit investment scenarios, which have included an alternative trend-based forecast for ridership growth since the 2010 edition. In the current report edition, however, all scenarios for highway and bridge investment assume aggregate growth in VMT at the rate forecast by an econometric model recently developed for FHWA. This forecast was judged more realistic than the aggregate growth rate based on the forecasts the States submit to HPMS, which evidence presented in Chapter 9 suggests has been over-predicting in recent years.

The base year of the analysis advances two 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, this issue is particularly significant for scenarios aimed at maintaining base-year conditions. Comparability across C&P report editions is also limited by changes over time in the analytical tools and data sets used in generating the scenarios.

The Economic Approach to Transportation Investment Analysis

The methods and assumptions used to analyze future highway, bridge, and transit investment scenarios are continuously evolving. Since the beginning of the highway report series in 1968, enhancements to the highway investment scenarios have resulted from innovations in analytical methods, new data and evidence, and changes in transportation planning objectives. Estimates of future requirements for highway investment, as reported in the *1968 National Highway Needs Report to Congress*, began as a combined "wish list" of State highway "needs." As the focus of national highway investment changed from system expansion to management of the existing system during the 1970s, national engineering standards were defined and applied to identify system deficiencies, and the investments necessary to remedy these deficiencies were estimated. By the end of the decade, a comprehensive database, the HPMS, had been developed to enable monitoring of highway system conditions and performance nationwide.

In the early 1980s, a sophisticated simulation model, the HPMS Analytical Process (HPMS-AP), became available to evaluate the impact of alternative investment strategies on system conditions and performance. The procedures used in HPMS-AP were based on engineering principles. Engineering standards were applied to determine which system attributes were considered deficient, and improvement option packages were developed using standard engineering countermeasures for given deficiencies, but without consideration of comparative economic benefits and costs.

In 1988, the Federal Highway Administration embarked on a long-term research and development effort to produce an alternative simulation procedure combining engineering principles with economic analysis. The product of this effort, the HERS model, was first used to develop one of the two highway investment scenarios presented in the 1995 C&P Report. In subsequent reports, HERS has been used to develop all the highway investment scenarios.

Executive Order 12893, "Principles for Federal Infrastructure Investments," issued on January 26, 1994, directs that Federal infrastructure investments should be based on a systematic analysis of expected benefits and costs. This order provided additional momentum for the shift toward developing analytical tools that incorporate economic analysis into the evaluation of investment requirements.

In the 1997 C&P Report, the Federal Transit Administration introduced the Transit Economics Requirements Model (TERM), which was used to develop both of the transit investment scenarios. TERM incorporates benefit-cost analysis into its determination of transit investment levels.

The 2002 C&P Report incorporated economic analysis into bridge investment modeling for the first time with the introduction of NBIAS.

The Economic Approach in Theory and Practice

The economic approach to transportation investment 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." For such analysis to be reliable, it must adequately consider the range of possible benefits and costs and the range of possible investment alternatives.

Which Benefits and Costs Should Be Considered?

A comprehensive benefit-cost analysis of a transportation investment considers all impacts of potential significance for society and values them in monetary terms, to the extent feasible. For some types of impacts, monetary valuation is facilitated by the existence of observable market prices. Such prices are generally available for inputs to the provision of transportation infrastructure, such as concrete for building highways or buses purchased for a transit system. The same is true for some types of benefits from transportation investments, such as savings in business travel time, which are conventionally valued at a measure of average hourly labor cost of the travelers.

For some other types of impacts for which market prices are not directly observable, monetary values can be reasonably inferred from behavior or expressed preferences. In this category are savings in non-business travel time and reductions in risk of crash-related fatality or other injury. As discussed in Chapter 10 (under "Value of a Statistical Life"), what is inferred is the amount that people typically would be willing to pay per unit of improvement, for example, per hour of non-business travel time saved. These values are combined with estimates of the magnitude of the improvement (or, as may happen, deterioration).

For other impacts, monetary valuation may not be possible because of problems with reliably estimating the magnitude of the improvement, placing a monetary value on the improvement, or both. Even when possible, reliable monetary valuation may require time and effort that would be out of proportion to the likely importance of the impact concerned. Benefit-cost analyses of transportation investments thus typically will omit valuing certain impacts that are difficult to monetize but, nevertheless, could be of interest.

The models used in this report—HERS, NBIAS, and TERM—each omit various types of investment impacts from their benefit-cost analyses. To some extent, this omission reflects the national coverage of their 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.

In addition, DOT will continue to explore other avenues for addressing impacts not captured by the suite of models used for the C&P report. One approach is to have the models represent impacts in ways that are sufficiently simplified to demand no more data than are available. This approach was taken to represent within HERS the impacts of traffic disruptions resulting from road construction. Another approach that DOT will continue to explore for the C&P report is to supplement the findings from HERS, NBIAS, and TERM with evidence from other sources. This approach could elucidate various environmental, health, and community impacts of highway and transit investments. Examples include environmental impacts of increased water runoff from highway pavements, barrier effects of highways for human and animal populations, health benefits from the additional walking activity when travelers use transit rather than cars, and other impacts related to livability. Another effect the DOT models do not consider, but which could be significant for some transportation investments, is the boost to economic competitiveness that results when travel times among competing producers are lessened. Faced with stiffer competition from rivals in other locations, producers may become more efficient and lower prices.

What Alternatives Should Be Analyzed?

Benefit-cost analyses of transportation investments need to include a sufficiently broad range of investment alternatives to be able to identify which is optimal. For transit and highway projects, this can entail consideration of cross-modal alternatives. Transit and highway projects can be complements, as when the addition of high-occupancy toll lanes to a freeway allows for new or improved bus express services; they can also be substitutes, as when construction of a light rail line lessens the demand for travel on a parallel freeway. In contrast, HERS and TERM each focus on investment in just one mode, and to incorporate a cross-modal perspective properly would require a major investment of time and resources, entailing major changes to the benefit-cost methodologies and the addition of considerable detail to the supporting databases. (As was noted above, the models' databases necessarily sacrifice detail to make national-level coverage feasible). For the foreseeable future, the best way to address this deficiency in future editions of the C&P report likely would be through review of evidence obtained from more regionally focused analyses using other modeling frameworks. Opportunities for future development of HERS, TERM, and NBIAS, including efforts to allow feedback between the models, were discussed in Appendix D of the 2013 C&P Report.

Beyond related cross-modal investment possibilities, economic evaluations of investments in highways or transit should also attempt to consider related public choices, such as policies for travel demand management and local zoning, or investment in other infrastructure. Several previous editions of the C&P report presented HERS modeling of highway investment combined with system-wide highway congestion pricing. Although the results indicated that pricing could substantially reduce the amount of highway investment that would be cost-beneficial, a review of the methodology in 2010 revealed significant limitations, which reflected in part the lack of transportation network detail in the HPMS database. The decision to exclude such modeling from the 2013 and current editions of the C&P report also took into account that the results would have been unlikely to differ from those reported previously, and that system-wide congestion pricing has yet to gain widespread public support.

A more limited form of congestion pricing is tolling on designated express lanes within a full access-controlled highway. When the tolling includes a discount or exemption for high-occupancy vehicles, such facilities are termed HOT (High Occupancy Toll) lanes. Over the past three decades, tolled express lanes have been implemented in urban areas across the United States and have been gaining popular support. Future versions of the HERS model could include a capability to analyze the costs and benefits of tolled express lanes and their effects on investment needs.

Measurement of Costs and Benefits in "Constant Dollars"

Benefit-cost analyses normally measure all benefits and costs in "constant dollars," that is, at the prices prevailing in some base year, typically near the year when the analysis is released. Future price changes can be difficult to forecast, and benefits and costs measured in base-year prices are more comprehensible.

In the simplest form of constant-dollar measurement, conversion of any quantity to a dollar value is done at that quantity's base-year price. Future savings in gallons of gasoline, for example, are monetized at the average price per gallon of gasoline in the base year (with the price possibly measured net of excise tax, as in HERS). This approach, still quite common in benefit-cost analysis, was the general practice in pre-2008 editions of the C&P report. It assumes any future inflation will change all prices in equal proportion, so that the ratios among prices will remain constant at their base-year levels. With relative prices constant, whether a benefit-cost analysis uses actual base-year prices or those prices are inflated uniformly at a projected rate of inflation is purely a presentational issue.

An alternative approach is warranted when significant changes in the relative price of a quantity important to the analysis can be predicted with sufficient confidence. What constitutes sufficient confidence is a judgment call, but some predictions carry official weight. The Energy Information Administration's *Annual Energy Outlook* forecasts changes in motor-fuel prices relative to the consumer price index (CPI) 25 years out. Starting with the 2008 C&P Report, the highway investment scenarios have incorporated these CPI-deflated forecasts. Since the 2010 edition, the C&P report also has incorporated CPI-deflated forecasts of the marginal damage cost of CO_2 emissions. Values for the marginal damage are those recommended by a Federal interagency working group for use in regulatory impact analysis. For this edition of the C&P report, the values

are taken from the 2013 update to these recommendations, which specify values for each year between 2010 and 2050.[1]

In this C&P report, the HERS modeling of highway investment also factors in the future growth in values of travel time savings. Such growth could be expected to result from future increases in average incomes: Notwithstanding periods of relative stagnation, the real incomes of Americans have increased over the long term and evidence indicates that people value their travel time more highly as their incomes increase. The growth rate assumed for the HERS modeling, 1.2 percent per year, was that stipulated in 2014 guidance for DOT on valuation of travel time savings for analyses with a base year of 2012. This assumption is a significant departure from the HERS analysis presented in the 2013 C&P Report, where growth in the value of travel time savings was included only as a sensitivity test and no growth was factored into the main scenarios.

Notwithstanding allowances for likely changes in prices relative to the consumer price index, the analysis in this report can be considered to measure benefits and costs in constant 2012 dollars. Office of Management and Budget guidance on benefit-cost analysis defines "real or constant dollar values" as follows: "Economic units measured in terms of constant purchasing power. A real value is not affected by general price inflation. Real values can be estimated by deflating nominal values with a general price index, such as the implicit deflator for Gross Domestic Product or the Consumer Price Index."[2]

Uncertainty in Transportation Investment Modeling

The three investment analysis models used in this report are deterministic, not probabilistic: 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 above, the analysis in Chapter 10 of this edition of the C&P report enables statements about the sensitivity of the scenario projections to variation in the underlying parameters (e.g., discount rates, value of time saved, statistical value of lives saved). As much as 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.

The relative level of uncertainty differs among the various projections made in this report. As already noted, the projections for all roads system wide are less reliable than those for Federal-aid highways. In addition, the projections for absolute levels of condition and performance indicators entail more uncertainty than the differences among these levels according to an assumed level of investment. For example, if speed limits were increased nationwide in the future, contrary to the HERS modeling assumption of no change from the base-year speed limits, this might significantly reduce the accuracy performance of the model's projections for average speed. At the same time, projections of how the amount of future investments in highways affects average speed could be

relatively accurate. Although investments in highway capacity expansion increase average speed, the increase will occur primarily under conditions of congestion when average speeds can be well below even the current speed limit. Under such conditions, an increase in the speed limit might have a negligible effect on the congestion reduction benefits of adding lanes.

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[1] Interagency Working Group on Social Cost of Carbon. May 2013. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866*, https://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf.
[2] OMB Circular No. A-94 Revised, http://www.whitehouse.gov/omb/circulars_a094.