Appendix D

Crosscutting Investment Analysis Issues

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Introduction

The 2008 C&P Report included an Afterword (Part IV) that comprehensively discussed limitations of the modeling and databases used for the report's analysis as well as possible remedies. This Appendix updates that Afterword by discussing recent progress and plans. It further explores select issues that recent developments have made more relevant. The economic slow-down from which the Nation is now emerging has stimulated interest in the impacts of transportation investments on aggregate employment and on U.S. economic competitiveness—impacts which have always been difficult to measure. The increased policy emphasis at the U.S. DOT on livability, sustainability, and maintenance of transportation assets in a state of good repair has likewise moved certain modeling challenges to the fore. The structure of the discussion in this appendix largely follows that of the 2008 C&P Report Afterword so that readers can more easily refer back to that section for discussion of the many issues that have not been revisited.

Conditions and Performance

Pavement Condition

In recent years, the Federal Highway Administration (FHWA) has collected and used data based on the International Roughness Index as its primary indicator for pavement condition. The advantages of this metric include objectivity and a focus on a condition that, by influencing ride quality, directly affects road users. Disadvantages include failure to adequately reflect pavement structural problems that do not manifest themselves simply through roughness. A related concern, particularly in light of ongoing efforts to improve the life of pavement improvements, has been that the pavement performance models in the Highway Economic Requirements System (HERS) do not reflect modern pavement design. As part of the recent Highway Performance Monitoring System (HPMS) reassessment, the range of pavement data to be collected was expanded to include information on other pavement distresses (fatigue cracking, rutting depth, faulting depth, and transverse cracking) as well as additional information regarding the structure of existing pavements. This new information will be used in the improved pavement deterioration models which, when incorporated into the HERS model, will provide increased accuracy in the determination of pavement service lives.

The initial phase of implementing the enhanced pavement equations was to test them outside the overall HERS model. That phase has been successfully completed; and the second phase, incorporation of the equations into the HERS model, has started. Upon completion of the second phase, testing of the HERS model will be conducted. The goal is to have the improved HERS model with the new pavement deterioration equations available in time to be reflected in the analyses presented in the 2012 C&P Report.

Prior to the incorporation of the new pavement deterioration equations into HERS, only two types of pavement improvements were considered: resurfacing and reconstruction. The addition of new pavement data items and performance modeling procedures will allow for additional pavement improvements to be considered, including different degrees of reconstruction, different levels of resurfacing, and less aggressive pavement preservation techniques. As discussed in Chapter 7, the investment scenarios estimated in this report are for capital expenditures only and do not include ongoing routine maintenance. However, both the FHWA and State departments of transportation are paying increasing attention to preventive maintenance strategies as a means of extending the useful life of pavement improvements. To the extent that such strategies are successful, they can reduce the need for capital improvements to address pavement condition deficiencies, an effect that the investment models should account for where possible. Future improvements to the HERS model based on these new data and equations should facilitate the evaluation of tradeoffs between more aggressive preventive maintenance strategies and capital improvements.

Transit Asset Reporting

The Transit Economic Requirements Model's (TERM's) assessment of transit capital needs for both asset preservation and service expansion are heavily reliant on data that document the asset holdings of the Nation's urban and rural transit operators. However, with the exception of agency passenger vehicle fleets, local transit operators receiving Federal transit funding are not required to report asset inventory data documenting the types, quantities, ages, conditions, or replacement values of assets they use in support of transit service. Therefore, to obtain asset inventory data for use in TERM, the Federal Transit Administration (FTA) must periodically submit asset inventory data requests to the Nation's largest bus and rail operators and a sample of smaller operators. Given the absence of any standards for asset inventory recording or reporting, the response to these requests provides inventory data in a variety of formats and at varying levels of detail and quality. Moreover, the asset holdings of those agencies that either do not receive or do not effectively respond to these requests must be estimated (based on the asset composition and age distribution of agencies of comparable size).

TERM's estimates of national capital investment needs would clearly improve with a system that requires transit operators receiving Federal transit funding to report their asset holdings on a consistent and regular basis. The data would be comparable to the vehicle data the operators already provide and to the reported highway segment and bridge data used by HERS and the National Bridge Investment Analysis System (NBIAS). Moreover, given the FTA's objective of better understanding, assessing and tracking the state-of-good-repair of the Nation's transit assets, the agency would benefit from the availability of data documenting the rehabilitation history of at least a sample of asset types (such as passenger stations and maintenance facilities). The FTA has made initial efforts in this direction with consideration of expanding the items local transit agencies report to the National Transit Database (NTD) to include the age and quantity of major asset holdings. In addition to the potential for significantly improving the accuracy of TERM analysis results, developing this type of transit asset reporting system would ensure greater comparability of results between editions of the C&P report.

Therefore, the FTA is in the process of developing a reporting requirement for the complete asset inventories from all transit rail agencies. This new reporting requirement will supplement passenger vehicles data already reported by the Nations' transit operators with comparable data for other asset types, including facilities, stations, track and structures, and control systems. However, this new reporting requirement is not expected to include data on asset conditions as this information is expensive to collect and difficult for the FTA to verify. Though this data collection effort is anticipated to start with the 2013 NTD reporting year, actual implementation will depend on transit agencies' response to the Federal Register Notice of Proposed Rulemaking and on the Office of Management and Budget's response to the Paperwork Reduction Act request.

Vehicle Speed

The FHWA continuously considers ways to improve the metrics used in the HERS model to summarize highway operational performance. For example, the 2008 C&P report introduced a new metric, adjusted average user cost, to avoid confounding the influence on user costs of projected fuel economy improvements with the influence of highway infrastructure. For future editions of the C&P report, another innovation could be an alternative measure of average highway speed. The measure currently used in HERS is a vehicle miles traveled (VMT)-weighted average of predicted speeds across the individual highway sections. Although some readers of the report wanting to calculate total vehicle-hours of delay may divide total VMT by this measure of average speed, this would not yield the correct result. For the calculation to be correct, one would need to calculate average speed simply as the ratio of total VMT to total vehicle-hours of travel (VHT). For future reports, the presentation of HERS results could include this alternative measure of average speed, which, in technical terms is the VHT-weighted geometric mean, and which would be lower than the VMT-weighted averages currently used.

Vehicle Operating Costs

Growing concerns about energy independence and the environment costs of vehicle emissions have stimulated interest in the impacts of highway investments and policies on fuel consumption. Unfortunately, the modeling of the impacts on road fuel economy and, more generally, on vehicle operating costs is an area in which highway performance evaluation models have lagged. HERS, along with various other models (e.g., the FHWA's project evaluation tool, BCA.net), has relied primarily on decades-old evidence (from as far back as the 1960s), including foreign evidence that is not easily generalized to U.S. scenarios. For the impacts of pavement condition on vehicle operating costs, a principal source of evidence remains the results of tests conducted in Brazil in the 1970s on pavements typically rougher than those on U.S. roads. For the impacts of vehicle speed on vehicle operating costs, HERS relies on evidence that is dated and sheds only limited light on the effects of congestion delay. These effects are sometimes conceptualized as stemming partly from a reduction in average speed and partly from an increase in speed variability due to stop-and-go driving conditions. Reflecting the limitations of the evidence on which it draws, the HERS model allows for the speed variability effect only on signalized roadways. A more complete account of this effect would also extend to stop-and-go conditions on unsignalized facilities and in work zones.

To chart a course for improving the HERS treatment of vehicle operating costs, the FHWA will be convening an expert panel during FY 2011. The research literature to be reviewed by the panel will include the forthcoming report on National Cooperative Highway Research Program Project 01-45, *Models for Estimating the Effects of Pavement Condition on Vehicle Operating Costs*. The panel will also investigate the potential use of the Motor Vehicle Emission Simulator (MOVES) model, the EPA's state-of-the-art tool for estimating emissions from motor vehicles. Among the improvements over the MOBILE6 modeling software it replaced (from which the current emissions equations in HERS were derived), MOVES can predict the emissions of greenhouse gases (GHG) and energy consumption. Although these predictions do not factor in changes in pavement conditions, they are based on detailed modeling of the influence of vehicle operating speeds. This modeling takes account of the entire distribution of VMT by speed cycle, where a cycle describes the variation in speed over a short span of time. One of the questions for the review panel will be the feasibility of developing fuel consumption equations in HERS, which predicts only an all-day average speed, from this detailed modeling involving micro speed cycles. In common with MOBILE6, MOVES allow users to generate predictions when the only available indicator of the speed distribution is an all-day average, but the expert panel will need to evaluate this capability and its potential incorporation into HERS.

The review panel will also consider the possibilities for collecting additional field data for developing new vehicle operating cost equations. With the possibilities created by on-board vehicle computers, geographic information system (GIS)/global positioning system technologies, and other recent advances, the costs of collecting speed and fuel consumption data have declined dramatically, at the same time that data can be collected continuously, virtually second-by-second. Matching field data collected from the vehicles with the data on roadway characteristics would be more challenging, but is worth exploring.

Bridge Performance Issues

Future enhancements to NBIAS may provide the capability to take advantage of the GIS information in HPMS to permit integrated applications of the model and HERS. In costing the widening of a highway section, HERS already allows for the cost of widening the typical number of structures located on a facility of that type, but this allowance is relatively crude. By enabling NBIAS to identify the bridges on a particular HPMS section, such a linkage would also enable this replacement of this estimation procedure by a more accurate estimate derived from NBIAS. Also importantly, when HERS selects a particular highway section for widening, the link will enable NBIAS to update its database to reflect the associated improvements to the bridge. Since the models currently are run independently, NBIAS can select a bridge for replacement or rehabilitation to address deficiencies that have already been remedied as part of a widening project selected by HERS. Linking the two models could also enable improved identification of functional deficiencies on bridges, for example due to curvature characteristics on adjacent sections of highway, on which the HPMS includes data.

NBIAS rehabilitation and replacement investment analyses are based on major bridge component data from the National Bridge Inventory (NBI) on major bridge components; in many cases the data are aggregated from more detailed element-level data. Because the structural deterioration models used in NBIAS are employed at the element level, element conditions must be inferred from the aggregated component data. The need for such inferences would be avoided if the NBI reported the data at the element level.

Even without such detail being added, planned enhancements to NBIAS will more fully exploit available information:

1. **Preventive maintenance, repair, and rehabilitation (MR&R).** For most structural elements, NBIAS currently selects only bridges that have reached the worst or next-to-worst state of repair for MR&R actions. Consequently, the model allows bridges to deteriorate to a "structurally deficient" condition without prescribing any work. Thus, the planned enhancements to NBIAS include the development of a more aggressive model, starting with validation of the new model's usability followed by the changes needed for calibration.
2. **Measurement of bridge user costs.** Originally designed just to minimize agency costs, the NBIAS model was modified to minimize user costs only for deck elements. Additional modifications being planned will determine the time cost to bridge users that result from a broader set of deficiencies, structural (e.g., deck, superstructure and substructure) as well as functional. The time cost, formally measured by a "mean time to service interruption" (MTSI) will, in concept, allow for disruptions resulting from a deficiency before being remedied (e.g., heavy trucks having to divert around a load-posted bridge) as well as from the remedial bridge work. The MTSI for each bridge can be adjusted to reflect traffic (level and composition), environmental, and other factors such as detour length and crash rates. For structural deficiencies, NBIAS currently differentiates user costs only as a function of bridge size, without considering traffic volumes or other factors.
3. **Allowance for aging effects.** The deterioration probability matrix in NBIAS currently takes no account of bridge age. The probability that a bridge element will deteriorate from one state to another depends only on the element's current condition. Current plans for revising NBIAS include the incorporation of element age into the new MR&R model to be developed. Such an enhanced model would present deterioration probabilities as two-parametric Weibull functions of time (instead of constants, as they are now) and to develop an iterative procedure that will deliver a solution to the Markov decision model with accelerating deterioration probabilities. A separate effort would calibrate the Weibull curves so that the time-average deterioration pattern remains in line with the existing constant-rate deterioration pattern.

For the consequence of service interruption, a set of characteristics could be identified to determine the importance of the bridge to the overall highway network. These characteristics likely would include ADT, percentage of trucks, detour distance, etc. A range would be established for each characteristic and, after consideration of all characteristics, a given bridge can be placed within a spectrum of low to high consequence. The consequence rating can then be combined with the estimated probability of a bridge experiencing a service disruption, to establish the rating of each bridge on a risk criticality scale. Ratings would be calculated using the latest NBI data and available tools, and stored for use during NBI simulations. Later, the criticality models could be built into the main NBIAS system.

Since criticality is expressed in relative terms without monetary value, it cannot be factored into a benefit-cost ratio (BCR). One way to incorporate risk into NBIAS is to allow criticality to take precedence over an incremental BCR. This means that funds will be distributed first among the most critical bridges (in decreasing order of project incremental BCR), then among the next most critical, etc. An option could allow the user to select whether or not to use the enhanced risk model during a simulation.

Vehicle Emissions

The version of HERS used for this report added to the model's outputs the predicted emissions of greenhouse gases from consumption of gasoline and diesel fuel. As discussed in Appendix A, the measurement is limited to CO_2, which accounts for 95 percent of the global warming potential of vehicle emissions. Since CO_2 emissions are a function of the amount of fuel consumed, the potential improvements to the HERS equations for fuel consumption (discussed above) would also enhance the modeling of GHG emissions. As detailed in the 2005 Technical Report on the HERS-ST model, the HERS methodology for estimating vehicle emissions of other types (e.g., carbon monoxide, sulfur oxides, nitrogen oxides, and fine particulate matter) relies on the MOBILE6 model. For the 2012 C&P Report, FHWA plans to update this methodology to be consistent with the emission equations in the EPA MOVES model, which has replaced MOBILE6.

Transit Conditions, Reliability, and Safety

TERM's condition decay curves have provided an effective means of assessing current asset conditions and expected future conditions under alternative investment scenarios, but the FTA and the transit industry in general would benefit from an improved understanding of the relationship between asset conditions and key outcome measures such as service reliability, safety, and transit ridership. It is helpful to note in this context that the intended outcome of the FTA's heightened focus on state-of-good-repair is not to have assets in good condition per se, it is rather to ensure good quality, safe, reliable, and cost-effective transit service. Research and understanding on the relationships between condition and other outcome measures would also improve understanding of the merits of investment scenarios considered in future editions of this report.

Transit Vehicle Crowding by Agency-Mode

Given the nature and granularity of transit operating data as currently reported to the National Transit Database, most TERM analysis on transit operating performance is limited to the agency-mode level of detail (e.g., Houston metro bus is considered as a single agency-mode). Given this limitation, TERM is not capable of determining whether some or any portions of an agency-mode's existing service (e.g., specific rail lines or bus corridors) are in need of transit capacity improvements. Rather, TERM must assess expansion and performance improvement needs for the agency-mode as a whole, without consideration of the performance of individual service corridors (this is in contrast to the highway segment HPMS data used by HERS). In this regard, TERM would benefit from the availability of corridor-level operational data (e.g., level of service supplied and service consumed), if only for a sample of the Nation's transit operators, with which to better assess transit operator expansion needs at the subagency-mode level of detail).

Transportation Supply and Demand

Transportation Costs

The modeling supporting the C&P report has normally measured all costs and benefits in constant base-year dollars. The underlying assumption is not that inflation will be absent, but that ratios among prices and unit costs will remain at their base-year levels. For example, this would imply that the cost per hour of travel time will remain in constant ratio to the cost of depreciation per vehicle-mile. By incorporating the U.S. Energy Information Administration (EIA) projections that motor fuel prices will increase sharply relative to overall level of consumer prices (as measured by the Consumer Price Index), the 2008 edition of the C&P report is the first to make an exception to the constant-dollar assumption. Technically, this means that the HERS analysis in this report measures all benefits and costs in constant 2008 *consumer* dollars. For example, an average user of travel projected at $1.103 per mile in 2028 (from *Exhibit 7-8*, 0.00% change in spending) means more precisely that the average cost will equal $1.103 of foregone consumer expenditure at 2008 consumer prices. Among other possible exceptions to the constant dollar assumption, the projections for values of time and construction costs would warrant particular consideration in future modeling.

Cost of Travel Time

Although changes in relative prices are hard to predict—for example, the Malthusian fears widely held in the 1960s and 1970s that relative prices of food commodities would skyrocket have not been realized thus far—one trend that has characterized the broad sweep of modern economic history has been rises in real per capita incomes and wages. In the United States, some statistics have pointed to average real wages growth being stagnant over the past few decades, but a 2007 analysis from the Minneapolis Federal Reserve Bank showed a different picture after more careful selection of a consumer price index and factoring in supplements to wages. The supplements, which include employer contributions to employee pension and insurance funds and employer contributions to government social insurance (but excluding benefits such as paid leave that are included in the U.S. Bureau of Labor Statistics' estimates of average hourly earnings), have generally been increasing as a share of employee compensation and reached an estimated 30 percent in 2005. This upward trend has resulted in no small measure from the rapid increase in the relative cost of health insurance, a common employee fringe benefit. Based on the measurement approach taken in the Minneapolis Federal Reserve Bank paper, it has been estimated for this report that average employee compensation per hour increased between 1995 and 2008 at a real rate of 1.8 percent. In Chapter 10, this estimate provided a rationale for the sensitivity test that increased the average value of travel time by 25 percent above the estimate for 2008. However, this test adopted the same higher value of time for each year in the 2009–2028 analysis period. A more realistic sensitivity test would allow for annual growth in the average value of travel time.

Construction Costs

Allowing construction costs to change relative to consumer prices is another potential refinement for future C&P report modeling. Chapter 7 considered a wide range of potential growth rates in real spending on highways, including at the high end annual increases of 5.90 percent, which would mean a boost of 49.6 percent after only five years. In the Chapter 9 supplemental analysis where the timing of investment is BCR-driven, spending can ramp up even more dramatically toward the start of the analysis period. At the highest overall level of investment considered, an average of $105.4 billion per year, 37.4 percent of the 20-year investment total would occur within the first funding period, 2009–2013. That means that annual spending during those first five years would average $159.8 billion, nearly three times as much as the $54.7 billion actually spent in the 2008 base year.

In reality, a spending increase of this scale and speed would likely drive up prices for highway construction work relative to consumer prices. Even when unemployment rates are high, as at present, such increases in demand for highway construction could run up against short-run constraints on the supply of skilled labor and other specialized resources. At present, the looming wave of baby boomer retirements and the demand for American engineering expertise being generated by the infrastructure boom in developing countries are among the factors that could create shortages in the supply of skilled labor for U.S. highway construction projects, should demand for such labor increase substantially. To the extent that some of the spending levels considered in this report's modeling would run up against supply-side constraints, they would lead to higher costs for highway construction projects, contrary to the modeling assumption that these costs remain constant. In this respect, the projections for highway conditions and performance at relatively high levels of spending are overly optimistic.

Even without major demand-side pressures, future rates of inflation could differ significantly between industries engaged in transportation infrastructure construction industries and the economy generally. A forecasting exercise would need to consider the input cost structure of these industries, the expected rates of input cost inflation, and the likely rate of industry productivity growth. A profile of the highway, street, and bridge construction reports that labor accounts for 42.9 percent of the industry's costs, and materials 32.6 percent, with the rest attributed to miscellaneous expenses, such as equipment, services and supplies, rentals, and overhead (*Highway and Street Construction (Excluding Elevated Highways) Industry Report*; available at http://business.highbeam.com). The industry has also been characterized as relatively energy-intensive; together with the EIA projections for sharp increases in energy prices, this could suggest future upward pressures on the industry's output inflation rate relative to general inflation.

The industry's future productivity growth relative to the rest of the economy is also an important determinant of its relative inflation rate. An example of such growth is the significant advances in recent years in the development of long-life asphalt and concrete pavements. Common practice in forecasting industry growth combines reliance on expert assessments of future technology prospects with extrapolations from estimates of past rates of productivity growth. For the construction sector, however, the measurement of productivity growth is often made challenging by the lack of adequate price indices for the sector's output. For highway construction prices, the changeover from using the FHWA Bid Price Index to using its successor, the National Highway Construction Cost Index, has created some uncertainty about the rate at which prices increased in the recent past, as was discussed in Chapter 10. Moreover, neither of these indices adequately reflects the decreases in quality-adjusted prices that result from technological advances such as the above-mentioned development of new construction techniques that make pavements longer-lived. For transit investment, matters are still worse: the transit industry does not even have a price index suitable for inflating historical costs to current or future levels. TERM's needs estimates and those of the transit industry in general would clearly benefit from the availability of a transit-specific capital cost index.

Such problems with the price indices hinder the measurement of past real growth in industry output, and hence of past productivity trends. Nevertheless, the prospects for future productivity growth in transportation infrastructure construction warrants consideration in the preparation of future C&P reports as part of an analysis of how construction prices are likely to change relative to consumer prices.

Crash and Emissions Costs

As was seen in Chapter 10, the HERS model with its current scope excluding targeted safety-focused investments produces projections that are not particularly sensitive to the assumed value of a statistical life. Directly modeling national investment needs for these types of improvements would require an entirely new approach, including the collection of additional or supplemental data and the development of new safety capital investment tools. The FHWA will be examining the possibilities for implementing these enhancements as part of its ongoing HERS model development program. Broadening the model's capabilities in these areas would strengthen the case for rethinking the current HERS assumption that the value of a statistical life relative to consumer prices remains unchanged over the 20-year analysis period. Since releasing its new guidance on the value of a statistical life in 2008, the U.S. DOT has updated the recommended value on the assumption of an elasticity of 0.55 with respect to the average economy-wide real wage. Incorporating a similar procedure into HERS and assuming future growth in real wages would produce projected values of statistical life that increase over the analysis period relative to consumer prices. In addition to this possibility, it would also be worth considering making similar changes to the HERS constant-dollar treatment of the cost per additional unit of vehicle emissions. EPA regulatory impact analyses project that these marginal costs will change over time relative to consumer prices as a result of growth in population and per capita incomes and changes in atmospheric concentrations.

Travel Demand

For highways as well as transit systems, the model-based projections presented in Part II of this report are sensitive to variations in assumptions about future travel demand. These assumptions are embodied in the forecast rates of growth in travel demand that are input to the models, as well as the elasticities that adjust these forecasts for projected changes in the travel cost or service quality that users experience. Areas of potential refinements to the treatment of travel demand include the modeling of congestion pricing and of demand management strategies not modeled in this report, such as changes to land use policies. As well, the elasticities are in need of updating to be consistent with the most recent evidence and, possibly, restructuring to better allow for network effects.

Demand Management Impacts on VMT

For highways, the HERS model inputs the section-level forecasts of VMT from the HPMS, and interprets them as the outcomes that would occur if the average user cost of travel were to remain at its base-year level. According to the results in Chapter 10, if VMT were to grow over 2009–2028 at its recent historical rates rather than the overall percent rate implied by the HPMS projections, highway conditions and performance would be significantly improved at any given level of investment and the amount of potentially cost-beneficial investment over the 20 years would be significantly reduced. Although these sensitivity tests might be viewed as a rough proxy for the effects of future demand management policies other than congestion pricing (which is modeled in Chapter 10), it would be preferable for HERS modeling to directly incorporate meaningful estimates of these effects. A starting point could be the 2009 Transportation Research Board (TRB) Special Report, *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 Emissions*. The report found that more compact development has potential to substantially reduce VMT, with the literature suggesting that:

> *"…doubling residential density across a metropolitan area might lower household VMT by about 5 to 12 percent, and perhaps by as much as 25 percent, if coupled with higher employment concentrations, significant public transit improvements, mixed uses, and other supportive demand management measures."*

The TRB report also found that:

> *"Promoting more compact, mixed-use development on a large scale will require overcoming numerous obstacles. These obstacles include the traditional reluctance of many local governments to zone for such development and the lack of either regional governments with effective powers to regulate land use in most metropolitan areas or a strong state role in land use planning."*

As TRB further noted, the transportation planning models used by the MPOs and other agencies mostly have limited ability to predict the impacts of changes in land use policies. Future editions of the C&P report may be able to draw on evidence from the growing number of exceptions, such as the model developed at the Sacramento Area Council of Governments and the California statewide integrated land use/transportation model under development at Caltrans.

Price Sensitivity of Highway Travel Demand

As was discussed in Chapter 10, the HERS model contains elasticity parameters that quantify the sensitivity of travel demand (as measured by VMT) to changes in travel cost. A general elasticity describes a relationship at a system-level and measures both VMT and average cost per VMT for an entire highway network. HERS considers such general elasticities only as an input to the estimation of a section-level elasticity, which measures the change in the travel cost and associated VMT response for a particular highway section. The HERS procedure for deriving section-level elasticities distinguishes a VMT response that occurs through route diversion and a scale effect that captures the VMT response that would occur even without route diversion, simply as a result of the change in travel cost. To quantify the scale effect, the procedure takes the ratio of the section length to the average length of a highway trip—estimated to be 10 miles—and multiplies by the estimated general elasticity. (To illustrate, the modeling in this report assumed the general elasticity to have a long-run value of -0.8, so that for a section one mile in length the scale effect would equal -0.08 percent, meaning that a 10 percent reduction in travel cost on that section would generate approximately 0.8 percent additional VMT on that section in the long run.) This procedure is just one of various approaches that could be taken to quantify the scale effect. Among the alternatives that could be incorporated into the versions of HERS used for future C&P reports are approaches that would apply a general elasticity to model-predicted changes in average user cost at a metropolitan area or regional level rather the section level.

For the route diversion response as well, alternatives to the current section-level approach in HERS are worth exploring. Currently, for a change in travel cost on any one section, the model predicts the change in VMT on that section alone. Impacts on VMT on other sections are implied by the allowance for route diversion but not incorporated in the model's analysis of other sections' conditions, performance, and investment needs. In addition, while the implied impacts are such that a reduction in travel cost on one section will attract traffic away from other sections, this presumes that the others sections form part of an alternative route; when other sections form part of the same route as the section where travel costs declines, VMT can be expected to increase on all these sections. Unfortunately, because HERS relies on data from only a sample of highway sections (from the HPMS), no amount of tinkering with the model can produce an altogether satisfactory allowance for network effects, but it may nevertheless be possible to improve on the current allowance.

Transit Ridership Growth Forecasts

For prior editions of this report, TERM's estimates of the investment expansion needs for transit were founded solely on the rate of growth in transit demand (passenger miles traveled [PMT]) as projected by the Nation's Metropolitan Planning Organizations (MPOs). In the past, some observers have expressed concern regarding this use of the MPO forecasts to generate unconstrained expansion needs estimates as these PMT growth projections are themselves generated based on financially constrained travel demand models (i.e., MPO PMT growth projections make assumptions regarding the level of potential future funding for transit capital improvements, including how those funds will be distributed between various modes and projects, with subsequent impacts on the rate of growth in transit ridership within each urbanized area). Hence, when used by TERM, the MPO growth forecasts effectively represent constrained PMT growth projections that are used to project unconstrained transit capital expansion needs.

This report edition has addressed this issue by labeling expansion needs based on MPO projections as a "Low Growth" scenario and by also introducing a "High Growth" scenario based for each urbanized area on its historical average rate of growth in PMT since 1999 (overall, high rates of PMT growth are roughly 60 percent higher than the low, MPO-projected rates). Future editions of the C&P report might consider other approaches to projecting PMT growth for assessing future transit capital expansion needs.

Congestion Pricing

In 2010, the FHWA convened an expert panel to evaluate the HERS-based modeling congestion pricing in the 2008 C&P Report and to recommend enhancements to this modeling for future applications. The panel found the foremost limitation of the modeling to be the current lack of capability in HERS to predict the impact of peak-period charges on the distribution of traffic across the day. HERS relies on the HPMS database, which reports only the all-day traffic volume. For the purpose of estimating recurrent traffic delay, the model distributes each section's daily traffic volume between the peak and off-peak periods, and then distributes the peak-period volume between the dominant and non-dominant directions of traffic (termed "peak" and "counter-peak"). The equations for estimating these distributions take account of the section's volume-to-capacity ratio, to allow for the well-known phenomenon of "peak spreading" and the "directional factor" reported in the HPMS database. To model peak-period congestion charges, however, would require elaborating this framework to include the influence of the cost of traveling in different periods on time-of-day travel decisions.

In addition to the inclusion of pricing effects on travel time-of-day decisions, the expert review panel recommended various potential improvements to the modeling of congestion pricing undertaken for the C&P reports. Some of these recommendations relate to fundamental limitations of the HERS model. As discussed above, HERS analyzes sample sections quasi-independently of each other, rather than conducting an integrated analysis of all sections on a highway network. This limitation made it difficult for panelists to interpret the section-level price elasticities and to evaluate the allowance these elasticities make for network effects (the inclusion of a route diversion response). Related recommendations were to (1) reconsider the estimation of the section-level elasticities to ensure consistency with the general elasticities, (2) get elasticity estimates based on route characteristics to capture network effects, and (3) update the HERS values for the general elasticities on the most recent evidence. The recommendation to update the general elasticities derives from the datedness of the evidence on which the current values are based (pre-2000) and will be implemented in time for the 2012 C&P Report. Progress on the other two recommendations concerning the elasticities is also possible, but will inevitably be limited by the non-network nature of the HERS model.

For future C&P reports, an addition to HERS-based modeling of congestion pricing could be case studies of potential pricing schemes in particular metropolitan regions, using transportation planning models that represent the region's entire network. Case studies of this sort have already been conducted for several areas, including the Washington DC and Puget Sound regions, with the modeled forms of pricing varying among and within studies from the more limited such as time-of-day varying tolls on managed lanes to more comprehensive forms similar to what has been considered in the C&P reports. Another potential advantage of this approach for addressing congestion pricing in future C&P reports concerns the treatment of traffic dynamics. HERS, in common with many traditional transportation planning models, produces measures of performance only over a lengthy period, such as average speed over a 3-hour afternoon peak. An incipient trend, however, is toward transportation planning models that represent conditions on a network dynamically, in successive time intervals of only a few minutes or less. The inclusion of such dynamics has the potential to substantially improve modeling to predict the impacts of congestion pricing. Indeed, evidence from the research literature suggests that, for maximum effectiveness, congestion charges may need to vary finely over a peak period, and that such charges may affect VMT quite differently from charges that are uniform over the peak (but otherwise set optimally).

That said, case studies of congestion pricing in metropolitan areas have thus far shed relatively little light on what is a key focus of this report's analysis, the impacts of pricing on highway investment needs, and the suitability of the available transportation planning models for estimating these impacts would need to be investigated. On the plus side, the multimodal coverage of many MPO models holds promise for investigating the impacts of congestion pricing on both highways and transit investment needs. In addition, while most of the models lack an in-built benefit-cost analysis capability, they can be used with benefit-cost postprocessors to evaluate investment needs. On the minus side, in contrast with HERS, many of the transportation planning models suitable for analyzing congestion pricing may not be designed for evaluating investment needs for pavement rehabilitation; with their typical origins as travel demand models, they are more suited for evaluating investments in highway capacity, which influence travel demand much more than pavement condition.

Another recommendation of the expert panel was to include the impacts of congestion pricing on vehicle operating costs. The HERS-based modeling undertaken for the C&P reports predicted impacts only on the travel time component of highway user cost, which can be attributed to the datedness and other limitations of the model's current equations for vehicle operating cost. As was discussed above, the FHWA is about to initiate the exploratory first stage of research to develop new equations with greater predictive power for use in HERS. These improvements, some of which may be implemented in time for the 2012 C&P Report, may also help advance the treatment of vehicle operating costs in models other than HERS. Lastly, the panel also called for consideration of the impacts of congestion pricing on non-recurrent congestion delay, which results mainly from traffic incidents. The HERS treatment of congestion pricing currently considers only the impacts on recurrent congestion delay, which results from the normal interaction of heavy traffic volumes and limited roadway capacity.

The expert panel's final report will be made available at http://www.fhwa.dot.gov/policy/otps/index.htm. Among the various other recommendations included is consideration of the impacts of congestion pricing on the rate of incident delay. The current congestion pricing procedure in HERS takes account only of what the model terms "congestion delay"—recurring delay that results from the routine presence of heavy traffic volumes. In the HERS equations, reductions in the ratio of traffic to roadway capacity—which congestion would produce—reduce the rate of incident delay (hours per thousand VMT), but the current congestion pricing procedures do not incorporate this component of the model.

Analytical Issues

Life-Cycle Cost Analysis

In addition to estimating the economically optimal level of future investment, an ideal investment analysis tool should be able to address the optimal timing of that investment by comparing the life-cycle costs of alternative temporal improvement strategies. It should also be able to quantify the tradeoffs between early, less aggressive improvements and deferred, more extensive improvements. While the input costs and modeled or assumed improvement lives used in the current investment models are intended to reflect the full life-cycle costs of improvements, this area remains a significant limitation on the methodology in use.

Each tool currently used by the FHWA and the FTA models system investments on a year-by-year (or period-by-period) basis. Although the improvements made in one period affect the condition of the system and improvement options available in subsequent periods, and the benefits of these improvements are evaluated over multiple periods that an improvement is in use, potential improvements in different time periods are not compared with one another. For example, while a particular improvement on a highway section may be justified on economic grounds, it could be more advantageous to postpone the improvement until a later time. The models do not currently consider this option, nor do they consider the potential effects of advancing certain actions. For the HERS model, however, the FHWA convened an expert panel in 2009 to consider potential modifications that would overcome these limitations. The initial steps that the panel decided on are in the process of implementation, though a new version of HERS that more fully optimizes the timing of improvements may not be ready in time for the 2012 C&P Report.

The HERS model is also limited by the way that it evaluates pavement improvements. The decision on whether a resurfacing improvement or full-depth pavement reconstruction is warranted is currently a mechanical one, based solely on whether the pavement condition is above or below a threshold reconstruction level. Ideally, such a decision would be made based on a tradeoff analysis between the less aggressive resurfacing option and the more expensive (but longer-lasting) reconstruction.

New Technologies and Techniques

Vehicles powered by alternative fuel technologies are expected to substantially increase their share of the U.S. vehicle fleet over the coming years. For the light-duty vehicle (LDV) fleet, EIA projections for 2030 put this share at 23.1 percent in the Reference Case scenario and 27.3 percent in the High Oil Price scenario, up from 1.8 percent in 2008. In each scenario, two technologies account for more than 89 percent of the alternative fuel LDVs: ethanol flex engines, which can run on gasoline or a blend of up to 85 percent ethanol and are currently common in Brazil; and electric-gasoline hybrid engines, which are currently found in a variety of models sold in the United States. Although electric vehicles are now making their debut on the U.S. market (e.g. Nissan Leaf and Chevy Volt), they and natural gas-powered vehicles face significant challenges in penetrating the LDV market; hence, neither of these technologies figure significantly in the EIA projections.

Incorporating alternative fuel technologies into HERS would require major revisions and supporting research efforts. The applications of HERS in this report indirectly make a crude allowance for their effect on vehicle fuel costs through the use of projections for the EIA "fuel efficiency indicator." This indicator corresponds to the average miles per gallon (MPG) measure for conventionally powered vehicles, except that the denominator is expressed in fuel gallon *equivalents*—that is, the gasoline usage that would consume an amount of energy (British thermal units or BTUs) identical to the energy actually consumed by all vehicles, including those powered by alternative fuels. To incorporate the EIA projections into the HERS model, this report's analysis has treated the efficiency indicators as though they measured average MPG for vehicles powered by the conventional fuels (gasoline and diesel fuel), since they are the only fuels the model recognizes. For using HERS model to predict the fuel component of vehicle operating cost, this simplification entails a certain loss of realism: an alternative fuel that consumes X percent more energy per unit than a gallon of gasoline will not necessarily cost X percent more per unit.

The omission of alternative-fueled vehicles from HERS also raises questions about the way the model allows for the influence on vehicle operating costs of highway conditions and performance. Traffic congestion, for example, could affect the energy consumption differently for conventional and alternative-fueled vehicles. As part of the planned research to update the model's vehicle operating cost equations, the FHWA will be considering the possibilities for incorporating such differences into HERS. The newness of the alternative technologies viewed against the extreme datedness of the current equations for predicting vehicle operating costs for conventional technologies might seem to suggest that such an effort would take many years to complete. However, the major advances that have occurred in vehicle data collection technologies could considerably shorten the time required. For some technologies such as electric plug-ins, development of vehicle operating cost equations should probably be deferred until such time as they establish a significant market presence. For others, such as electric-gasoline hybrid engines, the market presence and prospects may already be sufficient to start now.

As with highways and bridges, the introduction of new transit technologies can impact the timing and cost of asset life-cycle events, including the cost of rehabilitation and replacement activities and an asset's expected useful life. These changes will in turn impact the level of reinvestment dollars required to preserve existing transit assets or to acquire and maintain expansion assets. A key example here is alternative-fuel bus vehicles (e.g., biodiesel, hybrid buses), which make up an increasing proportion of the Nation's overall bus fleet. Acquisition and replacement costs for these vehicles can be on the order of 50 percent higher than for conventional diesel buses, and the useful lives of some of these technologies have yet to be ascertained. New designs, materials, and internal diagnostic systems are similarly impacting bus vehicle replacement costs and may be impacting vehicle service longevity as well. TERM has been able to track the impact of new technologies on the costs of vehicles and some other transit technologies by tracking changes in average procurement costs over time, but investment needs assessment accuracy may benefit from a better understanding of the impact of these new technologies on asset useful life. Ongoing updates and revisions to TERM's asset decay relationships (based on on-site engineering condition assessments) is one approach to tracking changes in transit asset expected useful life.

Benefit-Cost Analysis Procedures

For some transportation infrastructure investments, the determination as to whether or not they are cost-beneficial may hinge on the relative benefits of the implementation of supporting measures such as changes in land use policies. In such situations, which would seem to be particularly relevant to transit investments, the benefit-cost analysis should in principle evaluate the transportation investments and supporting policies as a package. This requires a framework capable of realistically modeling the interaction between land use and transportation; of representing the influences of specific land use policies such as changes to zoning; and of meaningfully measuring net benefits to society taking into account the impacts on travel cost and accessibility, housing prices, employment opportunities, etc. Developing such a framework for a given region is no small order, but progress has been made with various models, including the above-mentioned statewide model under development by Caltrans. The U.S. DOT will continuously be reviewing work in this field for its implications for C&P report issues and modeling frameworks.

Productivity and Economic Development

Since the preparation of the 2008 C&P Report, economic challenges facing the United States have to some extent shifted interest in the economic impacts of transportation investments from the regional to the national level. Among the many indications of this shift is the emphasis on U.S. economic competiveness and export growth in the Administration's recent report, *An Economic Analysis of Infrastructure Investment* (prepared by the Department of Treasury with the Council of Economic Advisers [CEA], released October 2010). The report refers in this regard to the call in the President's National Export Initiative for the Departments of Transportation and Commerce to "work together and with stakeholders to develop and implement a comprehensive, competitiveness-focused national freight policy."

In contrast, while past C&P reports have provided a rich picture of the impacts of investment on highway and transit conditions and performance, they have not delved much into the national economic impacts of these investments. Chapter 8 in this edition takes an initial step in this direction by using input-output analysis to measure the short-run economic stimulus effect of transit investments. Yet nowhere does this report attempt to quantify the full range of national economic impacts of transportation investments.

In the past, the FHWA commissioned econometric research on the productivity impacts of highway investments using industry-level data on the national economy, similar to a number of other econometric studies cited in the Treasury-CEA report. However, the FHWA's recent experience with this line of research has been that it does not yield estimates of productivity gains that are stable with respect to reasonable changes in model specification or sample period. One possible interpretation of this problem is that the marginal returns from additional investment have declined over the years as the highway network has expanded, to the point where they have become difficult to econometrically decipher and pin down. (The possibility of this network maturation effect on marginal returns to highway investment was also noted in the Treasury-CEA report).

Whatever the cause of this problem with the econometric research, the FHWA is now looking into the alternative of conducting simulations with national economic models drawing on evidence from benefit-cost analyses. Among the potential candidates for the national economic model to be used is the USAGE-ITC model developed by the U.S. International Trade Commission and several proprietary models. A possible application of this approach for a future C&P report would be to enter selected results from the HERS simulations into a national economic model to estimate the long-term impacts of alternative levels of investment. Macroeconomic indicators used to measure these impacts could include, for example, export volumes and prices, real GDP, real investment levels, and the balance of trade. Of the results from the HERS model, the estimated impacts on the costs of truck travel would be particularly useful for such an exercise. For travel in passenger vehicles, the portion of cost savings that accrue on business travel would also be valuable input; however, since HERS does not estimate the cost savings by travel purpose, this would have to be approximated.

Although estimates of such macroeconomic impacts are of independent interest, they should not divert attention to the bottom-line questions of benefit-cost analysis. Among the issues the FHWA will be investigating is whether national economic modeling of transportation investment, in addition to providing estimates of such impacts, also has a role in benefit-cost analysis. In theory, such modeling should be capable of capturing some effects relevant to benefit-cost analysis that are missing from conventional analyses. For one thing, most benefit-cost analyses concern themselves only with the total benefits and costs without considering their distribution according to country of residence. The Office of Management and Budget guidance on benefit-cost analysis explicitly calls for a focus on U.S. residents, which is the population to which models of the U.S. economy relate. For another, national economic models have the potential to capture some of the market "imperfections" in the economy related to taxes and the inadequate competition. On the other hand, using the national economic models to perform benefit-cost analysis requires that they contain suitable measures to summarize net benefits, and devising such measures may not be straightforward. Moreover, the use of unsuitable measures, such as changes in real GDP, represents a risk in the use of these models.

Economic impact analysis tools other than national economic models may also have the potential for factoring some market imperfections into benefit-cost analysis of transportation investments. A classic argument is that by lessening the "tyranny of distance," transportation improvements promote competition. The benefits from the enhanced competition will generally not be picked up in conventional benefit-cost analysis frameworks, but in theory could be captured using broader frameworks such as regional economic models. A variant of this classic argument that has attracted much attention in recent years, and has found its way into benefit-cost analysis practice for transportation investments in the United Kingdom, concerns "agglomeration economies" that result from transportation improvements that cause competitors to geographically cluster. The U.S. DOT will be following the research on this topic, which may have particular relevance to transit investments, to gain a clearer sense of the contribution of agglomeration economies to the benefits from transportation investments, and the feasibility of reliably quantifying this contribution for benefit-cost analysis.