APPENDIX D

Crosscutting Investment Analysis Issues

Crosscutting Investment Analysis Issues

Appendix D of the 2010 C&P Report discussed limitations of the modeling and databases used for the report's analysis as well as possible remedies. Appendix D in this report updates that discussion with 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. Department of Transportation (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 Appendix D in the 2010 C&P Report; readers can refer back to that report's appendix 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 used the International Roughness Index (IRI) to describe the condition of the Nation's pavements. The IRI is an objective measure and pavement roughness directly affects road users by influencing ride quality. The current pavement performance models in the Highway Economic Requirements System (HERS) use an alternative measure, the Present Serviceability Rating, which is strongly correlated with IRI. However, the models are somewhat out of date with respect to pavement design and to structural pavement problems that do not manifest themselves through roughness alone.

Enhanced Pavement Deterioration Models

In the last several years, research in the fields of pavement management, pavement design, and the collection of pavement distress data has resulted in the development of new pavement design formulas, improvements in data collection, and better approaches to monitoring highway pavement conditions. The development of a Mechanistic Empirical Pavement Design Guide (ME-PDG) formula was sponsored by the American Association of State Highway and Transportation Officials and the FHWA through the National Cooperative Highway Research Program.

Applying the ME-PDG pavement design formulas in the context of the HERS model presents several challenges. The ME-PDG formulas require an extensive amount of data for use in designing pavements for individual highway projects; collecting such information on a national basis for all Highway Performance Monitoring System (HPMS) sample sections (whether they are currently under consideration for improvement or not) would have placed an excessive reporting burden on the States that would not be warranted for conducting an aggregate national-level analysis of systemwide needs. Even if the necessary input data were readily available, applying the ME-PDG equations in their original form within the HERS model would have significantly impacted the run time for the model, making it impractical from a C&P report development perspective.

An evaluation of the components of the ME-PDG formulas was conducted to determine the minimum number of data items required to predict general pavement performance at an aggregate level that would be more appropriate for pavement performance analysis at the national level. Based on this evaluation, it was determined the number of additional data items required to be reported by State DOTs could be limited from the more than 100 original ME-PDG inputs to less than 10. Some of the items needed related to date of construction, last rehabilitation/maintenance date, and pavement type; such items should be readily obtainable from project records. Other items vary with time and would need to be obtained through automated data collection and/or observation in the field, including pavement roughness (IRI), depth of rutting or faulting, amount of cracking present per mile (percent), and the total area of failure per mile (percent). In some cases, default values at the State level representing typical conditions or construction practices were deemed sufficient; this includes items such as dowel bar spacing and soil type. Based on feedback from a working group of State DOT representatives, it was determined that collecting this limited set of additional data items from States is feasible, particularly because many States routinely collect information of this nature as part of their own pavement management programs.

The evaluation of the ME-PDG's suitability for adaptation into the HERS model fed into the most recent formal reassessment of the HPMS. As a result, the HPMS was modified to begin collecting additional pavement information to support a set of simplified ME-PDG-based models in HERS. The simplified pavement deterioration equations have been added to the HERS model and initial testing has been conducted. However, the reporting of the new and revised pavement data items for 2010 HPMS highway sample sections by the States was not sufficiently complete to support full testing of the new pavement equations. Additional testing will be conducted on future HPMS submittals as States have time to better adapt to the revised HPMS reporting requirements. In addition, the underlying ME-PDG pavement design formulas have been revised subsequent to the versions originally adapted for use in HERS. The FHWA will be evaluating these ME-PDG revisions to determine the extent to which they would impact the simplified ME-PDG equations developed for HERS, and will adapt the simplified equations as necessary.

Preventive Maintenance Models

As discussed in Chapter 7, the investment scenarios estimated in this report are for capital expenditures only and do not include costs associated with preventive maintenance. However, the FHWA and State DOTs are paying increased 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.

The FHWA has research underway to classify different types of State preventative maintenance strategies into broad groups with similar costs and impacts to make it feasible to simulate them within the HERS model framework. This research also involves the development of procedures for determining the optimal types and timing of preventive maintenance actions to be considered, for assessing the impacts of different types of actions on the remaining pavement service life and on future pavement performance, and for estimating the impacts of preventative maintenance actions on routine maintenance costs incurred by highway agencies and on the costs experienced by system users.

Transit Asset Reporting

The Transit Economic Requirements Model's (TERM's) assessment of transit capital needs for both asset preservation and service expansion rely heavily 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 have not been 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).

This situation will be changing due to requirements in the 2012 surface transportation bill (Moving Ahead for Progress in the 21st Century [MAP-21]) for FTA grant recipients to report asset inventory and condition data to the National Transit Database (NTD). Work to roll out this new data collection is underway and FTA hopes to collect an initial round of asset inventory data when agencies report their 2013 data. These data will provide for significantly better estimates of long-term transit reinvestment needs and will ensure greater comparability of results across future editions of the C&P report and allow for establishment of meaningful performance goals and measures. Although 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 Operating Costs

Growing concerns about energy independence and the environmental 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, including foreign evidence that is not easily generalized to U.S. scenarios. The HERS equations for vehicle operating cost are based on the model of vehicle operating costs developed in a 1982 study by the Texas Research and Development Foundation (TRDF) (Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors by J.P. Zaniewski et al., TRDF, June 1982, prepared for FHWA). For the impacts of pavement condition on vehicle operating costs, the study drew on 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, the study relied on tests conducted on U.S. roads in the 1970s. Reflecting the limitations of the TRDF study, HERS does not fully allow for the effects of congestion delay on fuel consumption. 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. 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.

For each edition of the C&P report, the prices in HERS for vehicle operating inputs are updated to the base-year levels using the most suitable price indices available. Price indices specific to fuel and tires are available, but more general price indices are used for some of the other input categories (such as repair and maintenance), which causes some divergence between actual price levels and what HERS assumes. For fuel consumption, the HERS equations include efficiency factors that incorporate the percent changes over time in average vehicle fuel efficiency on U.S. highways. Because this adjustment only scales the equations without otherwise changing the parameters, it cannot capture fundamental changes over time in how vehicle speed and other factors affect fuel economy—for example, changes in the speed range at which fuel economy is highest.

To chart a course for improving the HERS treatment of vehicle operating costs, the FHWA has initiated a scoping study that generated a set of preliminary recommendations for improved modeling of fuel consumption. The recommended short-term option would make use of a vehicle fuel consumption simulation model, quite possibly VEHSIM, to develop relationships in HERS that would predict fuel economy on highway sections as a function of congestion levels, pavement roughness, and other section characteristics. The longer-term and more expensive option would improve modeling accuracy, particularly for trucks, by: (1) expanding the set of vehicle drive cycles, which characterize at different levels of congestion a typical second-by-second speed trajectory over a short time cycle; and (2) providing a more comprehensive profile of the vehicle fleet for modeling fuel economy at the fleet level. The vehicle simulation models have been developed to facilitate the design and optimization of individual vehicle models. They require information on many vehicle parameters such as engine size, transmission type, transmission shift logic, gearing, and vehicle weight, which increases accuracy but also the time and effort in profiling the entire vehicle fleet.

For the longer-term option, special consideration was given to using the EPA Motor Vehicle Emission Simulator (MOVES) model because it is currently the basis for the emissions equations in HERS and because of its widespread use and reputation. Indeed, for the 2011 Urban Mobility Report, the Texas Transportation Institute switched to estimating wasted fuel due to congestion based on regression analysis of results from the MOVES model simulations. (In previous years' editions of that report, the estimation was based on the results of field tests conducted in the 1970s in which fuel consumption was measured for vehicles driving on urban arterials.) On the other hand, the vehicle operating cost scoping study identified a number of limitations of the MOVES modeling of fuel consumption that would need to be addressed. In particular, the model's "operating bins" that describe vehicle operating conditions—i.e., the combination of drive cycles and amount of energy demanded (Vehicle Specific Power)—were found to be too coarse for HERS requirements. A consequence of this lack of detail is that the model tends to over-predict fuel consumption at high speeds.

Another phase of this vehicle operating cost scoping study is still underway, which involves the development of recommended options for enhancing the HERS treatment of vehicle operating costs other than fuel. A key reference in the related research literature under review is the National Cooperative Highway Research Program (NCHRP) Report 720, Estimating the Effects of Pavement Condition on Vehicle Operating Costs. Because this report considers impacts on fuel consumption among the other impacts of pavement condition, the focus partly overlaps with that of the completed first phase of the current FHWA study.

For fuel consumption and tire costs, NCHRP Report 720 presents research that calibrated the World Bank HDM 4 model to U.S. conditions using data from Michigan road tests. In common with the models being considered as platforms for revamping the HERS fuel consumption equations (e.g., MOVES, VEHSIM), the models of fuel consumption and tire costs within HDM 4 are "mechanistic," meaning that they draw on the theoretical laws of physics. In contrast, "empirical" models are developed purely from field tests and generalizing their results much beyond the context in which the tests were conducted (the year, country, etc.) is not viable. Mechanistic models can be adapted to different contexts through empirical calibration that is a generally less data-intensive than re-estimating a purely empirical model. As indicated above, the TRDF study model from which the HERS vehicle operating cost equations derive is largely empirical. For vehicle repairs and maintenance, for which models have generally been empirical, the NCHRP study took an approach that combined (1) development of a hybrid mechanistic-empirical model and (2) updating the TRDF study model using recent data on the vehicle fleets of the Texas and Michigan DOTs.

For fuel consumption, the results of the NCHRP study indicate that pavement condition as measured by average roughness has a significant effect. In the illustrations provided for medium-size cars, increasing the measure of roughness (IRI) from 1 to 3 meters per kilometer (equivalent to raising it from 63 to 189 inches per mile) increases fuel consumption by 4.8 percent. (This is the estimate after the calibration of the HDM 4 model to U.S. conditions; without calibration, the estimate is 2.6 percent.) To put these IRI values into context, the threshold for good ride quality identified in Chapter 3 is an IRI value of less than 95 inches per mile, and the threshold for acceptable ride quality is an IRI value of less than or equal to 170 inches per mile. Thus, an IRI value of 63 would be considered good, while an IRI value of 189 would not meet the definition of acceptable. In 2010, approximately one-half of vehicle miles traveled (VMT) on Federal-aid highways was on pavements with good ride quality, while 18 percent of VMT was on pavements with poor ride quality (i.e., ride quality that was less than acceptable).

Bridge Performance Issues

The National Bridge Investment Analysis System (NBIAS) model has undergone several enhancements since its first use to refine and improve its predictions of future funding needs for the Nation's bridges. A number of additional enhancements are under consideration.

Element Level Data Versus Summary Rating Data

The NBIAS model is capable of using detailed bridge element level data to conduct analysis of bridge conditions. If this level of detailed information is not available, NBIAS can generate element level data based on the types of summary ratings included in the National Bridge Inventory (NBI) by combining statistical models, engineering judgment, and heuristic rules to synthesize representative condition levels of bridge elements. The NBIAS model has been used to conduct analysis using databases compiled using one or the other of the two above methods but not using a database with both types of bridge data.

MAP-21 requires that States begin reporting element level data for all bridges on the National Highway System to NBI within two years of its enactment. (MAP-21 also requires that a study be conducted on the benefits, cost effectiveness, and feasibility of requiring element-level data collection for bridges not on the National Highway System [NHS].) This presents a challenge from an NBIAS perspective because the model cannot currently process a single database that contains element level data for some bridges and summary ratings for other bridges.

It would be possible to analyze two different databases (one with element-level data and one with summary ratings) separately and combine the results, but this would prevent direct investment tradeoffs between NHS bridges and non-NHS bridges to be considered. A better solution would be to adapt NBIAS to accept both types of data as inputs simultaneously; FHWA plans to pursue this option, and will adapt the software accordingly, if this approach appears to be viable from a programming perspective.

Linkages With HERS

Future enhancements to NBIAS may provide the capability to take advantage of the Geographic Information System information in HPMS to permit integrated applications of the model and HERS. Linking the two models could 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.

Currently, NBIAS does not increase the number of lanes on a bridge even when traffic volumes would warrant additional lanes. The issue of requiring additional lanes for bridges has been addressed indirectly by including costs associated with structures within the average cost per lane mile assumed in the HERS model for capacity expansion. Research is planned to add the capability for NBIAS to replace bridges with wider bridges when warranted due to traffic volumes; the widening costs assumed in HERS would be simultaneously reduced. It is anticipated that adding this capability to NBIAS will allow for a more accurate assessment of the benefits and costs associated with widening projects involving structures.

There are a large number of culverts under the Nation's roadways. Culverts are typically used to convey water under a roadway, but some provide for the movement of people or animals from one side of a roadway to the other. By definition, culverts with a length of more than 20 feet meet the criteria of a bridge and data for them is entered in the NBI. They require regular maintenance and, at some point in time, replacement. The costs associated with culverts are factored into the typical per-mile costs assumed in HERS. However, adapting NBIAS to directly analyze costs associated with culverts would generate more refined estimates of their deterioration, maintenance, and replacement needs. The FHWA is planning to initiate research that would lead to the addition of this analytical capability to NBIAS.

User Impacts

FHWA's long-term research plans for NBIAS include improving the model's ability to measure the impact of the loss of a bridge or the restriction of its load carrying capacity. One approach would be to develop a "Risk Factor" that would be merged with the other ranking factors in NBIAS to better prioritize bridges for maintenance or construction activities. Bridges in areas where the loss of service due to failure or access restriction would create a greater hardship for the traveling public would be assigned higher risk factors and could, possibly, be scheduled for work before other bridge projects.

Additional modifications being planned would determine the time cost to bridge users that results 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.

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 a state of good repair is not to have assets in good condition per se; it is rather to ensure quality, safe, reliable, and cost-effective transit service. Research on and understanding of the relationships between condition and other outcome measures would also improve the 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 NTD, most TERM analysis on transit operating performance is limited to the agency-mode level of detail (for example, 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

Cost of Travel Time

The valuation of travel time savings—equivalently, the costing of travel time—figures significantly in the benefit-cost frameworks of the models used in this report. For valuing person hours of travel time, the models basically conform to DOT guidance on this subject referenced in Chapter 10. In recommending certain average values of travel time by trip purpose, the guidance acknowledges the considerable uncertainty as to which values would be most representative, particularly in the case of travel for personal (non-business) purposes. The guidance also notes travel time reliability—being able to predict in advance how long a trip will take—to be a distinct and complex issue in the costing of travel time, but provides no specific direction regarding its measurement. This issue is closely related to the costing of delay due to highway incidents, which is a major source of unreliability of highway travel time.

The following discussion examines the state of research in relation to the potential refinement of the HERS valuation of travel time, focusing on valuation elements for which the U.S. DOT has not established official guidance. In addition to incident delay/reliability, it also considers the vexing question of how to value travel time savings for freight, for which HERS makes an allowance that some see as conservative.

Cost of Incident Delay

Crashes and other traffic incidents (including disabled vehicles) can produce delays that are very hard for travelers to predict or plan for, particularly when these incidents result in lane closures. The HERS model differentiates this source of delay from routine traffic congestion and from traffic control devices (on road sections lacking full access control). Via a preprocessor, the model incorporates growth over the 20-year analysis period in the deployment of selected types of highway operational/Intelligent Transportation Systems (ITS) enhancements, such as ramp meters, real-time traveler information systems, and incident management systems. The benefits of these enhancements are represented in HERS as reductions in incident and other travel delay and in accidents. On the other hand, HERS does not vet these enhancements with benefit-cost analysis. The need to assign a cost to incident delay time arises primarily from the model's use of benefit-cost analysis to screen potential expansions to highway capacity. In the model and reality, adding capacity to congested sections of roadway reduces the amount of incident delay per VMT. One of the reasons for this is that closure of a single lane due to an incident represents a smaller percent reduction in capacity when additional alternative lanes are available.

The practice in HERS, and in some other models, has been to value savings in incident delay at a premium above the value assigned to savings in ordinary delay. For HERS, the rationale is that the occurrence of incidents makes travel time less reliable, which increases the risk of early or late arrival and the associated inconveniences. Travelers can reduce this risk by adding buffer time to their travel plans, but this entails inconveniences of its own. The intention in HERS is to make a rough overall allowance for these inconveniences by including a premium in the cost attached to incident delay. This premium has been set at 2.0, meaning that HERS values incident delay time as twice the value for ordinary delay time. The premium for incident delay time also features in the ITS Deployment Analysis System (IDAS) model, which FHWA developed as a tool for cost-benefit analysis of ITS deployments; when incident delay was first added to the HERS model, IDAS was utilizing a premium of 3.0. Although this value was taken into account, it did not appear to have a strong empirical basis. When a value was set for HERS, it was decided that a more conservative value of 2.0 should be utilized.

The choice of the value of 2.0 for HERS was also guided by the findings of NCHRP Report 431, Valuation of Travel Time savings and Predictability in Congested Conditions for Highway User-Cost Estimation. The findings were largely based on stated preference experiments that asked travelers for their preferences among hypothetical travel alternatives. The alternatives differed in expected travel time and in either the reliability of travel time or the amount of travel time spent under congested conditions. Similar experiments were conducted with freight carrier participants, but these were based on a very small sample and yielded weaker results. In the models estimated using the stated preference data, the values of travel time and reliability vary with traveler characteristics and, depending on the model, other variables such as level of congestion and trip purpose. As the report noted, the application of these models in benefit-cost analyses of particular road projects requires data inputs that may not be readily available. As a fallback option that it considered broadly consistent with its findings, the NCHRP study proposed that benefit-cost analyses value travel time under severe congestion at 2.5 times the rate for other travel time.

These underpinnings of the valuation of incident delay in HERS leave considerable room for improvement. The rule of thumb from the NCHRP study relates to travel under severely congested conditions rather than to incident delay as such. Its cost premium is meant to allow for both the discomfort of travel under these conditions and the associated loss of reliability, whereas the HERS cost premium for incident delay is meant only to allow for the loss of reliability. Although incident delay results in congestion, HERS does not factor into its valuations of travel time the discomfort cost of traveling under highly congested conditions. To do so only for the congestion associated with incident delay would make the model internally inconsistent. To do so for severe congestion delay in general, including that resulting from recurrent congestion (traffic values being high relative to normal capacity) and from other sources, could be an option for future enhancement of HERS. However, available evidence is insufficient to reliably implement this refinement at present, and current U.S. DOT guidance does not provide latitude to differentiate values of travel time by level of congestion.

It must also be borne in mind that the data for the NCHRP study was collected on a particular corridor (SR 91) in Southern California in the 1990s. Additional research into the valuation of travel time and reliability has been conducted since, and some recent evidence indicates that the effect of congestion on the value of travel time may differ significantly between regions.

SHRP2 Research on Value of Travel Time and Reliability

Much of the recent U.S. research on this topic has been funded under the Transportation Research Board Strategic Highway Research Program 2 (SHRP2). One of the program's four primary research areas focuses on travel time reliability—specifically, on "developing basic analytical techniques, design procedures, and institutional approaches to address the events—such as crashes, work zones, special events, and inclement weather—that result in the unpredictable congestion that makes travel times unreliable." Recently completed Project C04, Improving Our Understanding of How Highway Congestion and Pricing Affect Travel Demand, produced a number of findings relevant to an evaluation of possible future directions for valuing travel time and reliability in HERS.

The SHRP2 study relied primarily on three types of data sources on travel patterns in the New York and Seattle metropolitan regions:

- **Household travel surveys.** For each region, the study conducted revealed preference modeling using data from household surveys that ask respondents to maintain a diary of travel undertaken by household members for one or two days. These data do not include information on non-chosen travel alternatives that were available to the survey respondents, nor on the travel times and costs related to the chosen and non-chosen alternatives. The study therefore inferred and imputed this information using representations of the highway and transit networks.
- **Stated preference survey** (Seattle region). Because this approach presents survey respondents with hypothetical choices in which the travel alternatives and their characteristics are specified, it obviates the need for imputing and inferring such information. Another advantage over revealed preference analysis is the quasi-experimental design. In revealed preference analysis, the modeled determinants of travel choices may be highly correlated, which hinders estimation of their separate influences. For example, tolled express lanes offer both lower average travel time and increased reliability; the influences of these factors on traveler choices between these and general purpose lanes may be hard to empirically disentangle. These advantages must be weighed against the drawbacks of the stated preference approach. Respondents may not interpret the hypothetical alternatives as intended, may have trouble relating to them, and may make choices in the real-world quite different from those made in the research experiment.
- **Experimental data.** The study also made extensive use of data from the Traffic Choices Study, which recruited Seattle region households for a unique experiment. Participants were given a real monetary budget, but then money was deducted from the account every time they used certain roads at certain

times of day and week. Respondents were given a pricing schedule and map, as well as an in-vehicle meter that showed the price whenever they were being charged. (More information can be found at http://www.psrc.org/transportation/traffic.) The resulting data set combines, to a large degree, the best of the other types of data sets: experimental design (in common with stated preference data) and observations on actual travel choices (in common with the household travel surveys).

Several of the study's findings are of particular interest from a HERS model development perspective. First, travelers place a significant value on travel time reliability as measured by the standard deviation of travel time, which the study found to be the measure that performed best in its models. The reliability ratio—the value of reducing the standard deviation of travel time by one minute divided by the value of reducing the average travel time by one minute—was estimated in the range 0.7 to 1.5.

Second, in contrast with NCHRP Report 431, the study did not yield consistent evidence of a congestion stress factor in values of travel time. This factor was evident in the modeling results obtained for the New York region, particularly for mode choice, but not in the results for the Seattle region. The report speculates that this difference stems from the overall level of congestion being higher in the New York region. As in the NCHRP study, the estimated models included the share of travel time under relatively congested conditions or a measure of travel time reliability, but not both. In the models that included the share of travel time under relatively congested conditions, the estimated impact of this factor would also have reflected to some extent the effects of travel time reliability because these two factors are correlated. In light of this, even the results for the New York region do not clearly confirm a significant congestion discomfort component in the cost of travel time.

Third, the study found that savings on average commuting time are generally valued more highly for longer than for shorter trips, as the U.S. DOT guidance had found to be the case in previous research. However, the SHRP2 study found that the pattern reverses when trip lengths become unusually long (over 40 miles), resulting in an inverse U-shaped relationship. In addition, for the value of travel time reliability, the findings indicated a relative dampening effect for longer trips.

These findings are suggestive, but future research using more advanced data sets and methods could yield significantly different results. Among the needed improvement that the SHRP2 study identified is more comprehensive and accurate measurement of travel time reliability. The main challenge is conducting the measurement on a trip origin-destination basis rather than for individual highway links. The study noted that measurement on this origin-destination basis is still in its infancy and its own method to be only a "crude surrogate" for real-world travel time variation. In particular, its method cannot fully address nonrecurrent sources of congestion (like traffic incidents). There is also a need for research that can empirically distinguish the effect of congestion on the value of time (the stress factor) from the value of travel time reliability.

A current SHRP2 Project L04, Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools, should help resolve a number of the outstanding issues, including how to measure reliability. Although the study for SHRP2 Project C04 found that the standard deviation of travel time worked best in its models, other research has argued both on conceptual and model-performance grounds for alternative measures such as buffer time (the difference between the median and an upper percentile travel time, commonly the 95th percentile).

Valuation of Travel Time for Freight

In a recent critique of the benefit-cost analysis used for a range of potential transportation improvement projects in the San Francisco Bay region, the Reason Foundation faulted as unrealistically low the values assumed for truck travel time savings. These analyses, which were conducted by the region's Metropolitan Planning Commission, used the values of travel time in the HERS model. Estimation of these values in

HERS is based on the resource cost approach described in Appendix A. The resource cost per hour of truck travel estimated for each cost component:

- Truck labor (the crew, usually just a driver)
- Vehicle capital cost (interest and time-related depreciation)
- Inventory cost of the truck cargo in transit.

Estimation of the labor cost component, based on average hourly cost and the average crew size, is relatively straightforward. In the vehicle capital cost, the estimate of time-related depreciation component may contain a fair amount of error, though it is unclear in which direction. The estimation procedure derives time-related depreciation as a residual after netting out the portion of depreciation that is mileage-related. Current and planned research to improve the HERS equations for vehicle operating cost should lead to significantly improved estimates of mileage-related depreciation and hence of time-related depreciation as well. The inventory cost of the freight in transit, calculated from the average value of the cargo and the interest rate, is likely a conservative allowance for the freight time cost. It does not include the costs of damage in transit from spoilage and could significantly understate the time cost for goods that cannot be stockpiled at the destination (e.g., custom orders).

In gauging the potential for error in the HERS values of truck travel time, one must consider the relative magnitudes of each component. Labor cost is the component that can be estimated with the most confidence and is also for the largest: for five-axle combination trucks, for example, it amounts to $23.34 per hour, or about three-fourths of the overall value of $31.44 per hour. Although the other components contain more scope for error, the errors would have to be substantial to translate into large errors overall.

So how large could the errors in the nonlabor components be? This question is somewhat difficult to answer from available evidence. For the time cost of freight, an alternative to the inventory interest cost calculation is to derive an estimate from stated preference studies that ask shippers about their preferences among hypothetical shipping alternatives. The association of Australian and New Zealand road transport and traffic authorities, AUSTROADS, incorporated such estimates into its 2010 guidance on values of truck travel time for use in benefit-cost analysis. The time cost of freight is a far larger component of these values than of those used in HERS. For five-axle tractor-trailer combinations, for example, AUSTROADS set the cost of freight per vehicle-hour at what was worth, in U.S. dollars, $16.13 for nonurban shipments and $31.79 for urban shipments, compared with $22.69 for the cost per driver-hour. (In 2010, the Australian dollar averaged $0.92 in U.S. dollars.) In comparison, for the same class of truck, HERS sets the time cost of freight at only $0.77 per hour versus a cost per driver-hour of $22.98.

Although this comparison might seem to suggest that HERS greatly understates the time cost of freight, the above-discussed limitations of stated preference analysis significantly limit the confidence that can be placed in the AUSTROADS estimates. Moreover, the authors of the stated preference analysis on which AUSTROADS drew describe their effort as a "first basis" for further research, and noted the need for larger samples for more statistical precision.

Other possible approaches to valuing truck travel time savings are stated or revealed preference analysis of truck carrier choices or application of logistic optimization models. The analysis of carrier choices usually takes the form of stated preference analysis. The sample of carriers providing the data for these analyses tends to be small relative to requirements for valid statistical inferences and may not be representative. Resulting estimates of the value of truck travel time savings can be strikingly large—for example, the NCHRP Report 431 estimated that carriers on average value an hour of transit saved between $144.22 and $192.83, and an hour lateness avoided at $371.33. However, the report itself described the findings as statistically weak. The Reason Foundation critique of the Metropolitan Planning Commission's analysis cited evidence from a recent academic study (Assessing the Value of Delay to Truckers and Carriers, Q. Miao, B.X.Wang, and T.M.

Adams, University Transportation Center for Mobility, July 2011, prepared for U.S. DOT Research and Innovative Technology Administration) that used both stated preference analysis and logistic optimization modeling to estimate values of truck time savings. The FHWA will be reviewing the results and methodology of this study more closely as part of a broader literature review. From an initial review, it does not appear that the stated preference analysis yields values much out of line with those in HERS. The optimization modeling yields higher values, but is based on illustrative data (commercial sensitivity makes actual data hard to obtain) for one particular metropolitan area (Houston).

Overall, the values of truck travel time in HERS would seem to be most reasonable that can be derived from available evidence. Given the limitations of the alternative approaches, the resource cost approach taken in HERS is preferable, particularly considering that the labor component of the value of truck travel time is likely the largest and can be estimated with reasonable confidence. The FHWA will monitor and assess new evidence that becomes available, although enhancements to the truck value of time will not necessarily rank among the highest priorities for HERS model development. Because traffic on Federal-aid highways consists preponderantly of light-duty vehicles, even allowing for trucks having a higher value of time, the results of HERS analyses may not be particularly sensitive to adjustments to the value of truck travel time.

Potential Improvements to HERS Valuation of Travel Time

In its program for HERS model development, the FHWA will carefully monitor the progress in research on travel time and reliability. Advances in computer and data collection technologies can be expected to contribute significantly to this progress. In particular, the developing global positioning system/probe vehicles and other distributed wireless technologies will facilitate collection of data on actual travel times and speeds on routes between origins and destinations. These data will allow measurement of travel reliability over entire trips, which matters far more to travelers than reliability on particular links traversed during their trips. (A particular link could have travel times that are unpredictable day-to-day, but deviations from what is normal could average out over the many links traversed in a trip, making the entire trip time relatively predictable.) For this reason, the SHRP2 study focused on trip reliability, as will most future research on the value of travel time and reliability.

The focus on trip reliability will create challenges in drawing on the results of such research to enhance the HERS model. HERS estimates travel time for the individual highway sections in the HPMS sample, and with some refinement could also estimate travel time reliability. On the other hand, since HERS is not a network model, it cannot perform such estimation for trips by origin and destination. Rough adjustments around this limitation may be possible, however, as is already done in the model's s treatment of induced demand (which makes rough allowance for route diversion).

The non-network nature of HERS is also an obstacle to differentiating values of travel time by trip distance. (For this reason, the model does not incorporate U.S. DOT guidance's recommendation to value personal travel time more highly when it is intercity rather than local.) However, additional evidence on the effect of trip distance could aid the interpretation of the model's results, particularly by highway functional class. (For example, long-distance trips likely form a particularly high share of traffic on rural Interstates.)

Future editions of the C&P report may include new or modified sensitivity tests regarding the value of travel time savings. One option would be to differentiate values of travel time by geography. The results from SHRP2 Project L04 confirm the strong effect of income on the value of travel time that many other studies have found. It is also known that incomes vary geographically and are typically higher in urban than in rural areas. HERS recognizes that highway improvement costs are higher in urban than rural areas, and to do likewise for the value of travel time would make for greater consistency. For growth in the value of travel time, modified sensitivity tests will eventually be needed to address future changes in technology. Driverless cars, for example, could reduce substantially the value of travel time savings by allowing travelers to undertake other tasks, including work, while in their vehicles.

Construction Costs

Allowing construction costs to change relative to consumer prices is another potential refinement for future C&P report modeling. In the Chapter 9 supplemental analysis where the timing of investment is driven by benefit-cost ratios, spending can ramp up dramatically toward the start of the analysis period. At the highest overall level of investment considered, an average of $86.9 billion per year over 20 years, 41.2 percent of the 20-year investment total would occur within the first funding period, 2011 through 2015. That means that annual spending during those first five years would average $143.2 billion, about 2.5 times as much as the $56.4 billion actually spent in the 2010 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, if demand for such labor increases 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. The industry has also been characterized as relatively energy-intensive; together with the U.S. Energy Information Administration projections for sharp increases in energy prices—relative to the consumer price index, a 45 percent increase between 2010 and 2030—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 of the 2010 C&P Report. 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.

The FHWA has initiated a scoping study to investigate possible approaches for performing such analysis. Among these approaches are econometric modeling (practiced in some States) and simulation with national economic models. The Global Insight model, for example, yielded forecasts of highway construction costs that indicated percentage increases between 2010 and 2016 above most forecasts of Consumer Price Index inflation. Another model that might be used is the United States Applied General Equilibrium (USAGE) model, which FHWA will be using to estimate economic impacts of changes in overall highway investment (as discussed later in this Appendix).

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. The assumptions in the current versions of the models have been described in Chapter 7 for HERS and Chapter 8 for TERM. NBIAS is less sensitive to travel demand than the other two models.

Highway VMT Forecasts

The HERS model uses as a baseline the section-level forecast of VMT in the HPMS sample. FHWA has recently initiated a study to investigate the forecasting procedures being used by the States, on which HPMS Field Manual provides only general guidance. The manual requires a forecast for each sampled section, "which may cover a period of 18 to 25 year periods from the data year of the submittal." On choice of methodology, the manual allows wide latitude ranging from projections of existing trends to forecasts from travel demand models. Based on the findings about current practice, the study underway will assess options for changing the guidance and the HERS model assumptions. The goals of recommended changes will be increases in forecasting accuracy and consistency among forecasts or between them and the HERS model assumptions.

The procedure in HERS for adjusting the baseline forecasts assumes values for two types of demand elasticities: general and route diversion. Conceptually, a general elasticity describes a relationship at a system level and measures both VMT and average cost per VMT for an entire highway network. The modeling in this report assumed the general elasticity to have a long-run value of -0.8, meaning that a 1.0-percent reduction in travel cost systemwide would generate approximately 0.8 percent of additional VMT systemwide in the long run. For short-run responses, the model assumes a general elasticity of -0.4. These values are somewhat lower than those originally assumed based on review of related research conducted over a decade ago. The values were reduced starting with the 2006 C&P Report because some of the more recent research at the time seemed to point toward lower values.

As the first phase of a study to enhance the HERS treatment of induced demand, FHWA undertook an effort to re-estimate general elasticity based on a full review of relevant evidence. The review was completed in 2012 but too late to adjust the demand in light of its findings, which pointed toward elasticities close to those originally assumed: -0.6 for the short run and -1.2 for the long run. Some of the evidence reviewed came from models in which demand for travel depended on household income as well as the cost of travel. The effect of household income was found to be positive; as noted in Chapter 10, HERS would need to be modified to reflect this effect because it currently treats growth in travel time costs related to growth in household income in the same manner as it would an increase in travel time cost resulting from increased congestion, operating through the elasticity mechanism in HERS to reduce travel demand. The second phase of the study on induced demand will consider ways to deal with this inconsistency was well as the problems in modeling induced demand within a non-network model. Appendix D of the 2010 C&P Report described in detail the current representation of induced demand in HERS.

Transit Ridership Growth Forecasts

For all but the 2010 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). Observers have always expressed concern regarding this use of the MPO forecasts to generate unconstrained expansion needs estimates because these PMT growth projections are themselves 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.

As in the 2010 edition, this edition of the C&P report 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, which is 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. Additional understanding of the factors that determine demand for transit services is needed.

Productivity and Economic Development

A better understanding of how transportation investments affect the economy continues to be a priority for FHWA research. MAP-21 emphasizes the importance of transportation to improve economic efficiency. It requires the U.S. DOT to establish a national freight network and develop a national freight policy that will improve the condition and performance of the national freight network to provide the foundation for the United States to compete in the global economy, with goals to improve economic efficiency. This would require FHWA to develop performance measures that track freight movement and economic activity.

In the 2010 C&P Report, Appendix D discussed a developing shift in FHWA's approach to modeling the national economic impacts of highway investment. Earlier econometric studies of productivity gains from highway investment yielded estimates that were unstable with respect to reasonable changes in model specification or sample period. One possible explanation 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.

An alternative approach that is now being explored is simulation with national economic models drawing on evidence from benefit-cost analyses. After analyzing the capabilities of various macroeconomic models (econometric, input-output, and computable general equilibrium), the USAGE model has been selected for further testing and development. USAGE is a 500-industry dynamic computable general equilibrium model of the U.S. economy developed at Monash University in collaboration with the U.S. International Trade Commission. It was the only model that satisfied all of the following criteria important for estimating the economic effects of transportation investments:

- The freight-carrying modes are represented as separate industries, and substitution between modes can be represented.
- The model can represent a change in the productivity of each freight mode through a change in the highway (or other modal) capital stock input it utilizes, or in the technical parameters defining the productivity of the industry. Further, changes in prices of the freight services influence demand for those services, consistent with economic theory.

- The model allows for prices and demand to adjust in response to changes in taxation policy (primarily fuel and income taxes).
- The model can account for short-term Keynesian effects of government spending under the presence of slack resources (i.e., stimulus effects).

The USAGE model will be run using the outputs of the HERS model as its inputs to estimate the economy-wide impacts of increased investment in transportation infrastructure, as well as other transportation policy scenarios. In contrast with this focus on national-level impacts, other research has been investigating the impacts of highway improvements on State, regional, or local economies—for example, the SHRP2 Projects C03 (Interactions between Transportation Capacity, Economic Systems, and Land Use merged with Integrating Economic Considerations Project Development) and the follow-on SHRP2 project C11. Although the focus of such research is not directly related to the HERS model, the results would be useful for other modeling, possibly including application of the State-level version of HERS, HERS-ST, which is maintained by FHWA.

Another research study looked at the relationship between transportation investments and the economy. Historically, the growth in VMT has mirrored the growth in the economy, suggesting a strong correlation between the two. A literature search was conducted to find the current state of knowledge on the relationship between growth in Gross Domestic Product (GDP) and VMT. Current literature on this subject is limited and the evidence is inconclusive on the direction or the nature of this relationship. Understanding how changes in VMT affect GDP is important because some MPOs look to reduce VMT as a way to reduce the externalities of vehicle use including greenhouse gas (GHG) emissions, pollution, and roadway congestion. Alternatively, policies to attain lower GHG emissions could be achieved through the use of alternative fuel or technologies to improve fuel efficiency, and congestion reduction goals could be achieved by means other than reducing total VMT. Knowing how changes in VMT affect GDP could influence transportation policy decisions about congestion and GHG emissions.