Appendix A

Changes in Highway Investment Requirements Methodology

Investment requirements for highway preservation and highway and bridge capacity expansion are modeled by the Highway Economic Requirements System (HERS), which was introduced in the 1995 C&P report. This appendix describes the basic HERS methodology and approach in slightly more detail than is presented in Part II, including the treatment of high cost improvements, the allocation of investment across improvement types, and the calculation of the highway backlog. It also explores some of the improvements that have been made to the model since the 1999 C&P report, including changes in the travel demand elasticity procedures, congestion routines, emissions cost module, and the benefit cost analysis procedures.

Highway Economic Requirements System (HERS)

HERS initiates the investment requirement analysis by evaluating the current state of the highway system using information on pavements, geometry, traffic volumes, vehicle mix, and other characteristics from the Highway Performance Monitoring System (HPMS) sample dataset. Using section-specific traffic growth projections, HERS forecasts future conditions and performance across several funding periods. As used in this report, the future analysis covers four consecutive 5year periods. At the end of each period, the model checks for deficiencies in eight highway section characteristics: pavement condition, surface type, volume/service flow (V/SF) ratio, lane width, right shoulder width, shoulder type, horizontal alignment (curves), and vertical alignment (grades).

Once HERS determines a section's pavement or capacity is deficient, it will identify potential improvements to correct some or all of the section's deficient characteristics. HERS evaluates seven kinds of improvements: reconstruction with more lanes, reconstruction to wider lanes, pavement reconstruction, major widening, minor widening, resurfacing with shoulder improvements, and resurfacing. For each of these seven kinds of improvements, HERS evaluates four alignment alternatives: improved curves and grades, improved curves only, improved grades only, or no change. Thus, HERS has 28 distinct types of improvements to choose from. When analyzing a particular section, HERS actively considers no more than six alternative improvement types at a time: one or two aggressive improvements that would address all of the section's deficiencies and three or four less-aggressive improvements that would address only some of the section's deficiencies.

When evaluating which potential improvement, if any, should be implemented on a particular highway section, HERS employs incremental benefit/cost analysis. HERS defines benefits as reductions in direct highway user costs, agency costs, and societal costs. Highway user benefits are defined as reductions in travel time costs, crash costs, and vehicle operating costs. Agency benefits include reduced maintenance costs and the residual (salvage) value of the projects. Societal benefits include reduced vehicle emissions. These benefits are divided by the costs of implementing the improvement to arrive at a benefit/cost ratio (BCR) that is used to rank potential projects on different sections. The HERS model implements improvements with the highest BCR first. Thus, as each additional project is implemented, the marginal BCR and the average BCR of all projects implemented decline. However, until the point where the marginal BCR falls below 1.0 (i.e., costs exceed benefits), total net benefits will continue to increase as additional projects are implemented. Investment beyond this point would not be economically justified, since it would result in a decline in total net benefits.

Because the HERS model analyzes each highway segment independently, rather than the entire transportation system, it cannot fully evaluate the network effects of individual highway improvements. This was one of the limitations of the model was cited in a June 2000 report by the United States General Accounting Office (GAO), *FHWA's Model for Estimating Highway Needs is*

Generally Reasonable, Despite Limitations. While efforts have been made to indirectly account for some network effects, HERS is fundamentally rooted to its primary data source, the national sample of independent highway sections contained in the Highway Performance Monitoring System (HPMS). In order to fully recognize all network effects it would be necessary to develop significant new data sources and analytical techniques.

High Cost Capacity Improvements

For each highway section in the HPMS, States code a Widening Feasibility rating. The investment requirements analysis in versions of the C&P prior to the 1999 report treated this rating as a measure of the number of lanes that could be added at "normal" cost. It was assumed that if additional lanes were justified, they could be added at "high" cost, representing the cost required to double-deck a freeway, acquire especially expensive right-of-way, or build a parallel highway or other transportation facility. When HERS was developed, a procedure for adding capacity on sections coded as infeasible to widen was built into the model as an optional setting. For technical reasons at the time, this feature was turned off in HERS for the baseline runs made for the 1999 report, thereby assuming that highway sections could not be widened beyond the width specified as feasible by the States. Instead, new roads and bridges were treated as non-modeled spending, and their current share of highway capital outlays was added to the HERS results through the external adjustment procedures.

Subsequent improvements to HERS since the 1999 C&P have made the high cost capacity improvements feature more tenable for investment analysis, so this feature was turned on for the HERS runs made in this report. However, since much of the investment in new roads and bridges occurs in corridors parallel to existing routes, such capacity expansion is now considered to be captured by the improvements modeled in HERS, and external adjustments are no longer made for new highway facility expenditures when estimating future investment requirements.

Allocating HERS and NBIAS Results Across Improvement Types

Highway capital expenditures can be divided among three types of improvements: system preservation, system expansion, and system enhancements (see Chapters 6 and 7 for definitions and discussion). All improvements selected by HERS that did not add lanes to a facility were classified as system preservation. For improvements that added lanes, the total cost of the improvement was split between preservation and expansion, since widening projects typically improve the existing lanes of a facility to some degree. Also, adding new lanes to a facility tends to reduce the amount of traffic carried by each of the old lanes, which may extend their pavement life. The allocation of widening costs between preservation and capacity expansion was based on the improvement cost inputs and implementation procedures within the HERS model.

All investment requirements projected by the National Bridge Investment Analysis System (NBIAS) are classified as preservation only, since new bridge and bridge capacity expansion investments are implicitly modeled by HERS. HERS does not currently identify investment requirements for system enhancements.

Highway Investment Backlog

To calculate this value, HERS has been modified to evaluate the current state of each highway section before projecting the effects of future travel growth on congestion and pavement deterioration. Any potential improvement that would correct an existing pavement or capacity deficiency, and that has a benefit/cost ratio greater than or equal to 1.0, would be considered to be part of the current highway investment backlog.

As noted in Chapter 7, the backlog estimate produced by HERS does not include either rural minor collectors or rural and urban local roads and streets (since HPMS does not contain sample section data for these functional systems), nor does it contain any estimate for system enhancements.

Travel Demand Elasticity

The States furnish projected travel for each sample highway section in the HPMS dataset. As described in Chapters 7 and 9, HERS assumes that the HPMS forecasts are constant-price forecasts, meaning that the generalized price facing highway users in the forecast year is the same as in the base year. The HERS model uses these projections as an initial baseline, but alters them in response to changes in highway user costs on each section over time. The travel demand elasticity procedures in HERS recognize that as a highway becomes more congested, some potential travel on the facility may be deterred, and that when lanes are added to a facility, the volume of travel may increase.

The basic principal behind demand elasticity is that as the price of a product increases relative to the price of other products or services, consumers will be inclined to consume less of it. Conversely, if the price of a product decreases, consumers will be inclined to consume more of it, either in place of some other product or in addition to their current overall consumption.

The travel demand elasticity procedures in HERS treat the cost of traveling a facility as its price. As a highway becomes more congested, the cost of traveling the facility (i.e., travel time cost) increases, which tends to constrain the volume of traffic growth. Conversely, when lanes are added and highway user costs decrease, the volume of travel tends to increase.

As a result of travel demand elasticity, the overall level of highway investment has an impact on projected travel growth. For any highway investment requirement scenario that results in a decline in average highway user costs, the effective vehicle miles traveled (VMT) growth rate tends to be higher than the baseline rate. For scenarios in which highway user costs increase, the effective VMT growth rate tends to be lower than the baseline rate. This effect is discussed in more detail in Chapter 9.

Q. What are some examples of the types of behavior that the travel demand elasticity features in HERS represent?

A. If highway congestion worsens in an area, this increases travel time costs, which might cause highway users to shift to mass transit, or cause some people living in that area to forgo some personal trips they might ordinarily make. For example, they might be more likely to combine multiple errands into a single trip, because the time spent in traffic on every trip discourages them from making trips unless it is absolutely necessary.

In the longer term, people might make additional adjustments to their lifestyles in response to changes in user costs that would impact their travel demand. For example, if travel time in an area is reduced substantially for an extended period of time, some people may make different choices about where to purchase a home. If congestion is reduced, purchasing a home far out in the suburbs might become more attractive, since commuters would be able to travel further in a shorter period of time.

Demand elasticity is measured as the percentage change in travel relative to the percentage change in costs faced by users of the facility. Thus, an elasticity value of –0.8 would mean that a 10 percent decrease in user costs would result in an 8 percent increase in travel.

Changes in HERS Elasticity Procedures

The travel demand elasticity values used in this report are lower than the values used in the 1997 C&P report. The reason for this change is that the HERS elasticity procedures have been adjusted to directly account for some traveler responses to changes in user costs that were previously implicit in the higher elasticity values. These adjustments include:

- Divisibility. Some components of user costs are vehicle-specific and can be shared among vehicle occupants (such as fuel costs), while others are person-specific (such as travel time costs) and cannot be divided. If divisible costs were to increase, highway users could react by increasing their average vehicle occupancy rates, thereby dampening the effect of the cost increase on VMT. The elasticity procedures now reflect this effect.

- Section Length. The HPMS sample sections used in the analysis vary in their length, and the HERS calculations now take the length of each section into account in the elasticity routines. A given section of road will generally be used for only a portion of a vehicle trip. Thus, a change in user costs on a particular section will have a less-than-proportional effect on the overall cost of the trip. Changes in user costs on a particular segment would then in turn be expected to have a smaller impact on travel on that segment than would a more universal change in user costs (such as an increase in area-wide fuel costs). In general, travel on longer sample segments should represent a larger share of the total trip cost for vehicles using the segment, so the adjustment to elasticity now takes section length into account when calculating the effect of user cost changes on travel.

- Route Diversion. The magnitude of an elasticity value is greater if there are many close substitutes. In the case of highway segments, parallel and connecting routes may provide a reasonable substitute if user costs (e.g., congestion) increase on a segment, and some traffic may be diverted onto these alternate routes. Since route diversion is likely to be a better substitute to highway users than forgoing a trip entirely, the appropriate elasticity value will be higher if it includes route diversion. Since route diversion is now being modeled separately within HERS, the elasticity value used in the calculations has been adjusted downward.

The particular values of elasticity used in this report are within the ranges of the available literature on this subject, and are intended to reflect that a change in highway user costs will have both short term and long term impacts on travel demand. For short term elasticity (the impact occurring within 1 or 2 years), HERS now uses a value of -0.6. An additional elasticity value of -0.4 is used for the share of the additional long term adjustment that takes place within the 5-year funding period (and in subsequent periods).

HERS Congestion Analysis

The HERS analysis of traffic congestion on each segment has undergone a number of modifications to bring it up to date with the latest research in highway traffic engineering. Some of these changes have been linked to changes in the HPMS database used in the analysis. The estimation of travel delay in

HERS is now made for three different types of delay: routine congestion delay, zero-volume delay, and incident delay.

Congestion Delay

The HPMS now also includes data on the number of lanes in the peak direction during peak travel periods. This has permitted HERS to be modified to calculate capacity and congestion delay separately for three periods: peak period/peak direction, peak period/counter-peak direction, and the off-peak period. The result is a more refined estimate of total congestion delay on each segment.

Zero-Volume Delay

The HERS procedures for calculating the delay associated with traffic signals and stop signs have also been updated. This delay is now referred to as "zero-volume delay", since it would occur for each user even if there were no other vehicles on the road. It is now calculated separately as a component of total delay.

Incident Delay

One of the major changes to HERS highlighted within the report is the inclusion of estimates for delay due to traffic incidents. This type of non-recurring delay has not been previously considered by HERS or its predecessors when calculating highway user costs, and as such represents a new area of modeled user benefits that may be affected by changing traffic conditions and highway improvements. HERS calculates the projected incident delay as a function of roadway characteristics. When translating incident delay into travel time costs, the revised model also allows it to be valued at a user-specified premium over routine travel time, reflecting the greater disutility that highway users face when dealing with unanticipated delays (See Chapter 10).

Operations Strategies

The new congestion equations in HERS also allow highway operations strategies (such as intelligent transportation systems [ITS]) to have an impact on the estimates of delay. The investment requirements projections made for this report incorporated impacts from two such strategies into the calculations: advanced traffic signal control and incident management. The model currently considers only existing deployments of these two technologies. Future modifications to HERS will increase the range of operations impacts that it considers, including both currently implemented strategies and projections of future technology deployments.

HERS Emissions Cost Estimates

HERS includes changes in estimated costs associated with air pollutant emissions from motor vehicles among the benefits (or disbenefits) resulting from improvements to sample highway sections. The costs resulting from emissions of each air pollutant are the product of the rate (in tons per vehicle-mile) at which it is emitted by the mix of vehicles typically using sections of each type, and the estimated cost of damages to human health and property caused by each ton. For some types of vehicle emissions, these impacts are directly observed, while other emission types (which serve as precursors to other air pollutants) may have an indirect effect on the environment. In either case, the costs (measured in dollars per vehicle-mile) for each individual pollutant can be calculated and summed to determine the total cost of air pollutant damages caused per vehicle-mile of travel on each section type.

As part of the revisions to HERS made in preparation for this report, the emission rates for each pollutant emitted by motor vehicles were updated to reflect newly available data on the mix of vehicles typically using different classes of highways. The rates used in HERS were also affected by recent changes to EPA models used to estimate emission rates for different types of motor vehicles operating at various speeds. HERS' previous estimates of damage costs for different pollutants were adjusted only to account for price inflation; a comprehensive overhaul of pollution damage costs is planned as part of future model updates.

The first step in this process was to update the distribution of travel among seven vehicle classes for each of the nine highway section types used by HERS. These data were tabulated from estimates of the distribution of VMT among 13 vehicle classes and 12 roadway functional classes, derived from 1999 HPMS data (previous versions of HERS used vehicle distributions based on 1982 data). The 13 vehicle classes employed in the HPMS were consolidated into the seven HERS vehicle classes by comparing and matching as closely as possible the weight limits, vehicle body styles, and wheel configurations used to define individual vehicle classes in HPMS and HERS. The 12 functional classes used in HPMS were consolidated to the nine highway section types employed in HERS by discarding data for the lowest-order functional classes (which are not analyzed in HERS) and grouping the remaining functional classes.

At the same time, the 13 vehicle classes in the HPMS data were mapped into the 16 vehicle classes employed by the Environmental Protection Agency's recently-released MOBILE6 vehicle emission factor model, which estimates emission rates for gaseous air pollutants. Finally, the 13 HPMS vehicle classes were also consolidated further to the 12 vehicle classes employed by EPA's PART5 emissions factor model, which is used to analyze emissions of particulate air pollutants from motor vehicles. This was again accomplished by matching as closely as possible the weight limits and vehicle characteristics used to define vehicle classes in HPMS with those employed by the MOBILE6 and PART5 emission factor models. This process resulted in a detailed correspondence of vehicle classes among the underlying HPMS data on vehicle-miles of travel, the MOBILE6 and PART5 emission factor models, and the distribution of vehicle travel on each HERS highway section type.

Next, MOBILE6 was used to compute emission rates for carbon monoxide (CO), volatile organic compounds (VOC), and nitrogen oxides (NOx) by each of its 16 vehicle classes. Emission rates for these pollutants were computed at 5-mph increments at speeds ranging from 5 mph to 70 mph, and values for 1-mph increments were interpolated using the procedure recommended in guidance documents prepared by EPA for use of the model. The PART5 model was subsequently used to compute emission rates per vehicle-mile of travel for sulfur dioxide (SO_2) and particulate matter of varying sizes (PM2.5 and PM10) by each vehicle type; these rates are estimated by PART5 to be independent of vehicle speed.

Using the previously-developed correspondence among the vehicle classes used by HERS, MOBILE6, and PART5 (derived from their common linkage to the vehicle classes employed in the underlying HPMS data on VMT), the emission rates for individual vehicle classes were combined to produce composite emission rates of each pollutant for the nine HERS section types. Each of these composite emission rates is the weighted average emissions per VMT of a single pollutant caused by the mix of vehicle classes operating on one of the nine highway types employed by HERS. As indicated previously, emission rates for CO, VOC, and NOx vary according to the average speed of travel, while those for other pollutants do not. Composite emission rates for the same pollutant and average speed differ among HERS' nine section types because the mix of vehicle classes typically operating on each section type differs, reflecting their different locations (urban vs. rural) and functions in the highway system (freeway, arterial, or collector).

Finally, emissions per mile of each pollutant occurring at each speed were weighted by the estimated average cost of damages to human health and property caused by each pollutant. These estimated damage costs are the same as those used in the previous version of HERS, updated to reflect current prices; as with the previous version of HERS, damage costs for localized pollutants are scaled upward to reflect the higher population exposure to emissions likely to occur in urban areas. The resulting damage costs for each pollutant are then summed to determine total air pollutant damage costs per VMT at each speed on each of the nine HERS section types. Again, these costs vary among individual section types even for the same average speed of travel because the mix of vehicle classes typically operating on each section type is different.

Because air pollutant damage costs differ depending on the average speed of travel, improvements to a sample highway section that increase average speed (those that increase its effective capacity) can change damage costs per vehicle-mile. Starting at low speeds, increasing speeds typically reduce air pollutant emission rates and thus damage costs up to a speed in the 40-50 mph range, after which emission rates for some pollutants and thus damage costs from all pollutants combined increase fairly rapidly.

Total air pollution damage costs with the improvement in place are the product of the per-mile damage cost associated with the (higher) average speed on the improved section and annual VMT achieved after the improvement is made. Depending on how this total compares to air pollution costs without the improvement in place, changes in air pollution damage costs from improving a HERS sample section can represent an additional benefit of the improvement or a reduction in benefits.

HERS Benefit Cost Analysis

Two key modifications have been made to the structure of the benefit cost analysis that HERS performs when considering potential improvements, involving the length of the benefit cost analysis (BCA) period and the calculation of benefits accruing outside of the analysis period.

BCA Period Length

In previous versions of HERS, the initial screening of potentially cost beneficial improvements (in which each improvement was compared to a "do nothing" base case) was based on a 5-year BCA period. The length of subsequent comparisons among improvements was based on the expected lifetime of the less-aggressive improvement. In the updated version of HERS used for the analyses in this report, all benefit cost calculations are made on the basis of a 20-year analysis period.

One implication of the change in the analysis period length is that the calculated benefit cost ratios for some improvements may be much higher than would be estimated by earlier versions of the model. The reason for this is that the "do nothing" base case against which improvements are initially compared is much less tenable over a 20-year period than over a 5-year period (see sidebar), due to the increased pavement deterioration and traffic congestion that would occur over the longer period, resulting in a larger relative benefit from improving the roadway.

> **Q. What would the "do nothing" base case for benefit cost analysis used in HERS look like?**
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> **A.** To illustrate what would happen if no improvements were made over the entire length of the 20-year analysis period considered by HERS, the model was run with funding constrained at the minimum possible level ($1 million per funding period). The results of this "doomsday scenario" showed average pavement roughness increasing by over 300 percent, travel time costs increasing by over 160 percent, and total user costs more than doubling. Average highway speeds would drop from 42 to 16 miles per hour, and highway use would be so deterred that VMT would decline by 25 percent.

Remaining Service Life

A complete analysis of the benefits and costs of an improvement must include a measure of the remaining value of the improvement at the end of the analysis period. In previous version of HERS, the calculation of this "residual value" was based on the future costs of bringing a highway section up to the level of condition and performance that it would have attained had the improvement been implemented at an earlier time. For this version of the model, this calculation has been replaced with a simplified concept based on the remaining service life of the improvement at the end of the analysis period. The residual value is simply calculated as a "rebate" of a portion of the project's costs, based on the ratio of the remaining service life to the total service life of the improvement.