United States General Accounting Office

GAO

Report to Congressional Committees

June 2000

HIGHWAY INFRASTRUCTURE

FHWA's Model for Estimating Highway Needs Is Generally Reasonable, Despite Limitations

GAO

Accountability * Integrity * Reliability

GAO/RCED-00-133

Contents

Letter 3

Appendixes

Appendix I: Scope and Methodology 24
Appendix II: Description of the HERS Model 26
Appendix III: Results of Sensitivity Analyses Using the HERS Model 36
Appendix IV: GAO Contacts and Staff Acknowledgments 38

Tables

Table 1: Development of Highway Investment Requirements Report and FHWA's Models 8
Table 2: The HERS Model's Estimates for Highways 13
Table 3: Percentage Change in HERS Estimates Resulting From Changes in Input Data 36

Figures

Figure 1: FHWA's Projected Annual Highway and Bridge Investment Requirements, 1998 through 2017 7
Figure 2: FHWA's Road Classification System 9
Figure 3: Simplified Representation of the HERS Modeling Process 11
Figure 4: Sensitivity of HERS Estimate to Changes in Certain Assumptions 20
Figure 5: Schematic of Process Used to Create HERS Data 28
Figure 6: Simplified Representation of the Structure of the HERS Model 31

Abbreviations

DOT	Department of Transportation
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GAO	U.S. General Accounting Office
HERS	Highway Economic Requirements System
HPMS	Highway Performance Monitoring System
IRI	International Roughness Index
PSR	Present Servicability Rating

United States General Accounting Office
Washington, D.C. 20548

Resources, Community, and
Economic Development Division

B-284060

June 5, 2000

The Honorable Bob Smith
Chairman
The Honorable Max S. Baucus
Ranking Minority Member
Committee on Environment and Public Works
United States Senate

The Honorable Bud Shuster
Chairman
The Honorable James L. Oberstar
Ranking Democratic Member
Committee on Transportation and Infrastructure
House of Representatives

Transportation systems play a vital role in the nation's economy by facilitating the movement of people and goods. The United States has made significant investments in its transportation infrastructure. Effective management of this infrastructure depends in part on reliable methods for estimating the amount of continuing investment required for maintaining and improving the transportation system. In this context, the Congress has required the Department of Transportation (DOT) to report every 2 years on the nation's need for investment to maintain and improve the nation's highways and bridges. To help estimate these future investment requirements, the Department's Federal Highway Administration (FHWA) uses the Highway Economic Requirements System (HERS) computer model.

The Transportation Equity Act for the 21st Century (P.L. 105-178) directed GAO to evaluate and report to the Congress how the Department of Transportation determines highway investment requirements using the HERS model. Accordingly, this report describes (1) the methodology the model uses to generate its estimates of the nation's highway investment requirements, (2) the strengths and limitations of the model, and (3) the usefulness of the HERS estimates for deciding on federal investments in highway infrastructure. In reporting on investment requirements, DOT includes estimates for highways, bridges, and transit systems. This report focuses on highway investment requirements and the HERS model's portion of these requirements. We used a draft of DOT's latest *Conditions*

and Performance Report, dated January 10, 2000, as the source of DOT's estimated investment requirements for highways. DOT approved this report for issuance on May 2, 2000, without changes to this material. We reviewed the model's documentation and interviewed its developers and operators, evaluated the model using general economic standards for models of this type, interviewed experts in transportation modeling to obtain their views, and interviewed legislative and executive branch officials who use the model and its results. See appendix I for more information on the methodology we used and a list of the transportation modeling experts we contacted.

Results in Brief

The HERS computer model estimates investment requirements for the nation's highways by adding together the costs of highway improvements that the model's benefit-cost analyses indicate are warranted. In making its estimates, the model relies on extensive data on highway segments throughout the nation, such as pavement conditions and expected growth in traffic, which the states primarily collect and update. The model also uses information, such as vehicle operating costs and emissions, obtained from other sources. The HERS model uses the data to (1) project the future condition and performance of the highway system, (2) assess whether any highway improvements are warranted, and (3) select and implement appropriate improvements. Such improvements range from resurfacing a highway to adding lanes and are based on a comparison of the construction costs and the lifetime benefits of the improvement. Adding a lane to relieve projected congestion, for example, has benefits because the increased capacity can reduce travel time and vehicle operating costs. FHWA uses the HERS model to estimate highway infrastructure improvement costs for certain highways under several different scenarios. For example, under an "economic efficiency" scenario, the HERS model estimates that, for these highways, the cost of constructing improvements for which the estimated benefits exceed the construction costs would be about $48 billion per year (1997 dollars) out of FHWA's overall estimate of $94 billion in investment requirements for all roads and bridges. Similarly, under a "maintain current conditions" scenario, the HERS model estimates that for these highways, the least costly mix of improvements that would maintain the pavement condition of the highways at current levels (1997) would be about $29 billion per year, out of FHWA's overall estimate of $57 billion in investment requirements for all roads and bridges.

The HERS model has several strengths that make it a unique and reasonable tool for estimating a general level of national highway

investment requirements, but it also has some limitations that affect the precision of its results. A major strength of the model is its ability to assess the relative benefits and costs associated with alternative options for improving the nation's highway infrastructure. This is a significant improvement over FHWA's previous method, which used engineering standards to identify highway deficiencies and estimated the cost of correcting these deficiencies without regard to economic merit. In June 1999, the HERS model was reviewed by an expert panel, which found that FHWA has strengthened the model over time. The model has limitations, however, in that it (1) does not completely account for the effect of highway improvements on all other highways and modes of transportation; (2) does not fully account for the uncertainties associated with its methods, data, and assumptions; (3) relies on a computational "shortcut" to approximate the future lifetime benefits of an improvement; and (4) uses data that vary in quality. The overall effect of these limitations on the HERS estimates cannot be determined; however, they indicate a level of imprecision with the estimates. Although FHWA plans to improve the model by addressing the limitations in the computational shortcut and the data, transportation modeling experts generally agree that a more complete accounting of the interrelationships between all highways and transportation modes cannot be done with the current state of the art in transportation modeling. In addition, changing the model to account for the uncertainties in its methods, data, and assumptions would be costly.

HERS estimates can be useful as a general guide for the investment requirements of the nation's highways included in the model, such as rural and urban interstates, and for assessing relative investment requirements over time. Nevertheless, the limitations and inherent uncertainties associated with making forecasts prevent the estimates from being a precise forecast of highway investment requirements. FHWA includes the HERS estimates in its current report on the conditions and performance of the nation's highways, bridges, and transit systems. In the report, however, FHWA does not clearly disclose the level of uncertainties in the HERS estimates. Furthermore, to derive a total estimate of highway investment requirements, FHWA combines the HERS estimates with estimates for other types of highways and investments that are not based on benefit-cost analyses. As a result, the report's readers are not likely to be aware of the imprecision of the HERS estimates and the fact that only part of the total highway investment requirements is estimated on the basis of an assessment of the benefits and costs of alternative improvement options.

This report makes recommendations to improve the model's approximation of the future lifetime benefits of highway improvements and FHWA's disclosure of some of the uncertainties associated with the model's estimates in its report to the Congress. DOT generally agreed with these recommendations.

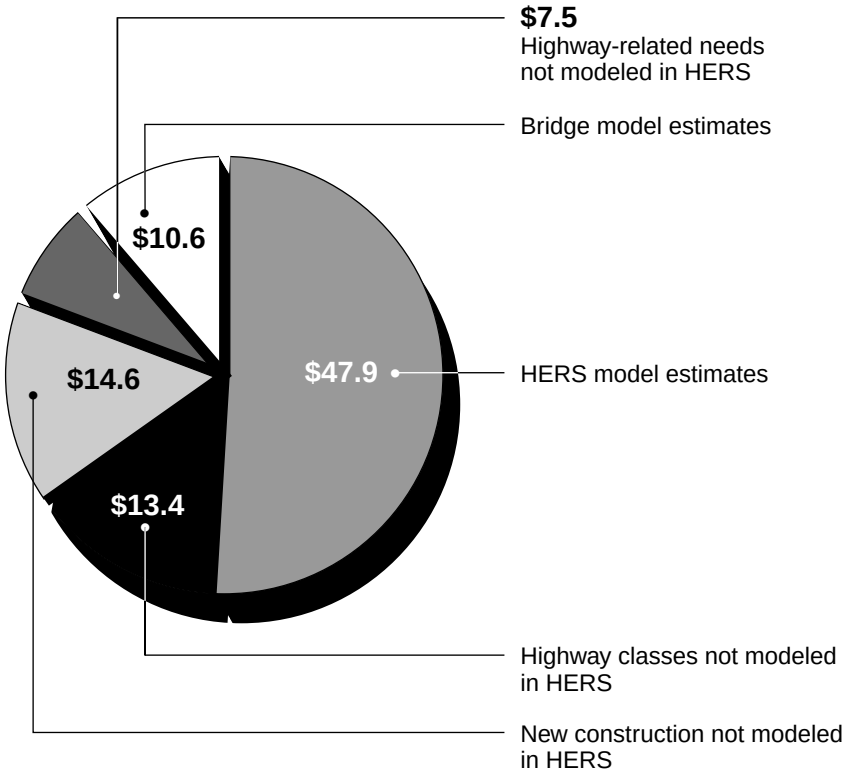
Background

DOT submits biennial reports to the Congress detailing the state of the nation's highways, bridges, and other surface transportation systems. The *Conditions and Performance Report* to Congress, known as the C&P Report, fulfills the mandate[1] for a report on future highway investment requirements that the Congress first established in 1965. The reports include forecasts of investment requirements for the nation's highways and bridges over the following 20 years.

FHWA's estimates of total highway and bridge investment requirements in the C&P Report combine estimates derived from the HERS model, a bridge model, and other types of estimates. The HERS model uses benefit-cost analyses to estimate future highway investment requirements on the basis of information about existing highways. On the other hand, the bridge model is based on engineering data and does not currently use benefit-cost analyses in estimating investment requirements for bridges. In addition, FHWA supplements these two estimates by including the cost of improving those highways not modeled in HERS. These costs include estimates for new highways, highway classes not included in the HERS model, and highway-related requirements such as safety enhancements, traffic operation improvements, and environmental improvements. FHWA estimates these costs by assuming that they represent a fixed percentage of the combined HERS and bridge models' estimate of investment requirements. The percentages are based on data from 1997 highway expenditures. Of the total highway and bridge average annual investment requirements identified in the C&P Report ($94 billion), only 51 percent are derived using the HERS model and its benefit-cost analyses. The remaining 49 percent are derived using either the bridge model or the fixed-percentage procedure. See figure 1.

[1] See 23 U.S.C. section 502(g) and 49 U.S.C. section 308(e).

Figure 1: FHWA's Projected Annual Highway and Bridge Investment Requirements, 1998 through 2017



Dollars in billions

Source: FHWA 1999 C&P Report.

The methodology FHWA uses to estimate highway investment requirements has changed since the first "wish list" of estimates was submitted to the Congress in 1968. The earliest estimates simply collected and reported investment requirements prepared by the states. In the early 1980s, the agency designed an engineering model that identified highway deficiencies and estimated the cost to improve them on the basis of engineering standards such as pavement deterioration and road design. Recognizing that a benefit-cost approach combined with an engineering model could yield a more defensible estimate of future investment requirements, FHWA began developing the HERS model in 1988. However, the agency used its engineering model exclusively to forecast highway

investment requirements until the 1995 C&P Report. This report incorporated one estimate based on HERS benefit-cost analyses and a second estimate based on the engineering model approach. Table 1 outlines FHWA's efforts to estimate highway investment requirements. According to FHWA officials, the HERS benefit-cost approach complies with an executive order[2] that requires federal spending for infrastructure to be based on a systematic analysis of expected benefits and costs.

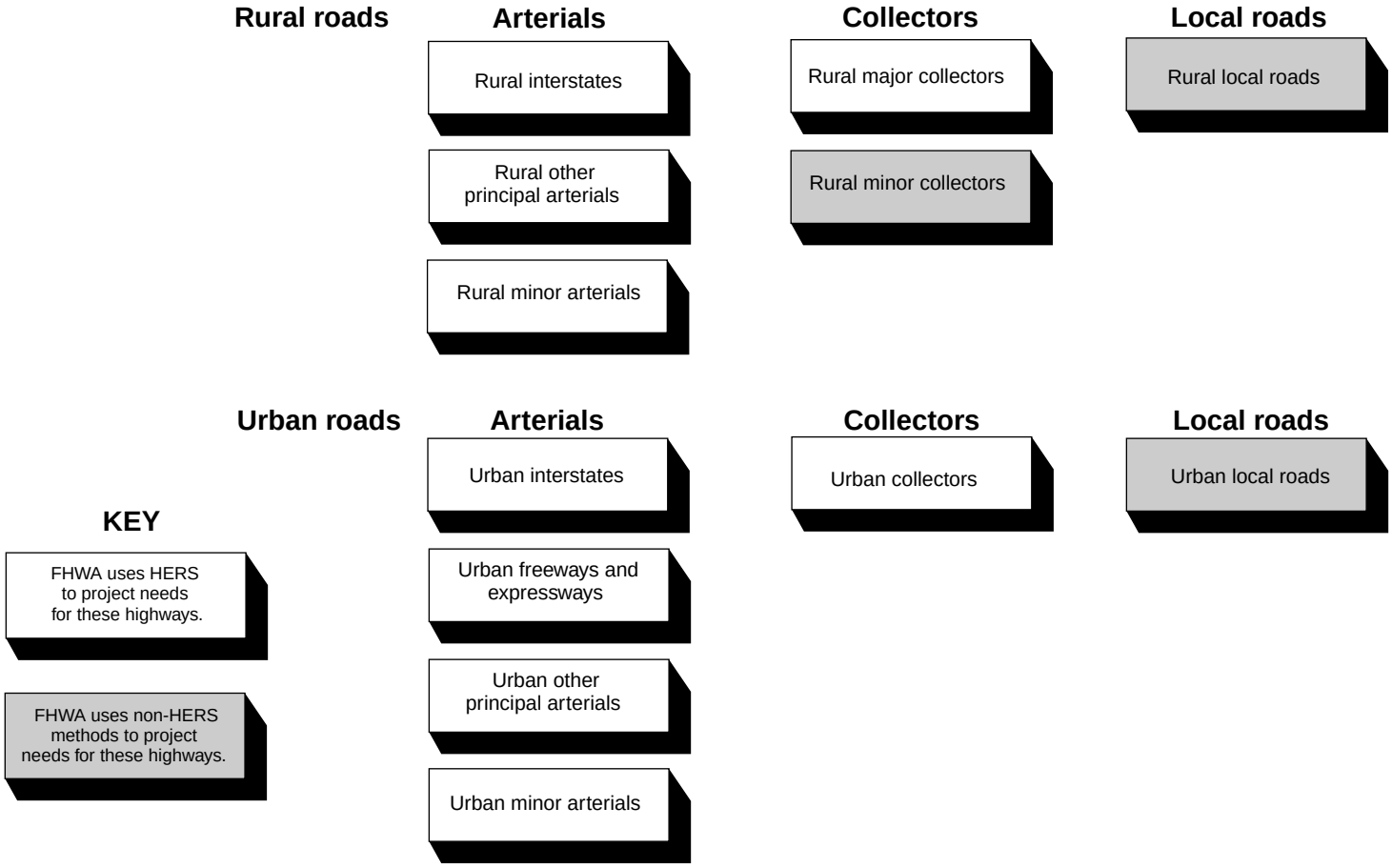
Table 1: Development of Highway Investment Requirements Report and FHWA's Models

Year	FHWA effort
1968	First FHWA highway investment requirements report (response to 1965 statutory requirement).
Early 1980s	FHWA designs model to estimate highway investment requirements using engineering standards.
1988 to 1994	FHWA develops HERS model, adding economic analyses to engineering-based estimates.
1995	First C&P Report to include HERS results.
1999	First C&P Report with environmental costs of vehicle emissions included in HERS results.

The HERS model estimates investment requirements for 9 of FHWA's 12 classes of roads—those that are included in the agency's database of highway conditions. FHWA classifies public roads in the United States into 12 categories. Area categories include rural and urban highways. Functional categories are arterials, collectors, and local roads. Arterials allow the highest traffic speeds. They often have multiple lanes and a degree of access control. Collectors are designed for lower speeds and shorter trips. They typically are two-lane roads that may extend into residential neighborhoods. Local roads are any roads below the collector system. Other categories distinguish roads by significance criteria, for example, interstate highways or major and minor traffic flows. Figure 2 shows which classes of roads are modeled in HERS.

[2] Executive Order 12893, Principles for Federal Infrastructure Investments (1994), discusses the importance of continuous infrastructure investment to sustained economic growth. The order directs federal agencies with infrastructure investment responsibilities to plan for investments using a systematic analysis of expected benefits and costs.

Figure 2: FHWA's Road Classification System



Source: GAO analysis of FHWA information.

From fiscal years 1995 through 1999, FHWA spent a total of $2.4 million on HERS support contracts. In 1999, FHWA spent a total of $677,345 on expenses related to the HERS model. For example, FHWA contracted to develop revised pavement information at a cost of $150,986. In addition, FHWA spent $350,000 on HERS support for the 1999 C&P Report, ongoing maintenance and operation of the model, and a study on the needs of the interstate highway system.

The HERS Model Uses Benefit-Cost Analyses to Estimate Highway Investment Requirements

To estimate future investment requirements,[3] the HERS model uses an extensive set of data on segments of highways throughout the nation to conduct benefit-cost analyses. The HERS model uses these data to forecast the condition and performance (congestion) of the highway segments over the following 20 years and to evaluate whether improving the segments is economically justified. The HERS model evaluates potential improvements on each segment by comparing their construction costs with their benefits, including reductions in travel times, vehicle operating costs, and accidents, to determine whether an improvement is warranted. FHWA uses the HERS model to estimate highway investment requirements under several different scenarios.

The HERS Model Relies on Extensive Data

To estimate investment requirements, the HERS model uses a database of information about highway conditions and performance submitted by the states. Using guidance developed by FHWA, each state collects and annually updates data on a sample of highways representing nine highway classes. These data include factors like highway capacity, average annual daily traffic, pavement roughness, and lane width. In total, the states collect and report to FHWA information on about 125,000 highway segments, ranging in length from one block to 10 miles. The states also develop forecasts of traffic growth on each segment. The HERS model uses "expansion" factors to generalize the estimated improvement costs for segments to the highway classes they represent.

In addition to the state-collected data, the HERS model uses other information that FHWA derives from various economic studies. For example, in estimating the benefits associated with highway improvements, the HERS model counts as a benefit any reduction in travel time brought about by the highway improvement. In making this calculation, FHWA uses hourly compensation data from the Department of Commerce's Bureau of Labor Statistics to quantify the dollar value of travel time saved by travelers on work-related trips. In addition, as currently modeled in HERS, highway improvements increase net traffic and hence total vehicle emissions. As a result, the HERS model subtracts the dollar value of the air pollution damages caused by vehicle emissions from the

[3] In using "investment requirements," we are referring to the HERS model's estimates of average annual infrastructure improvement costs for the nine highway classes included in the model.

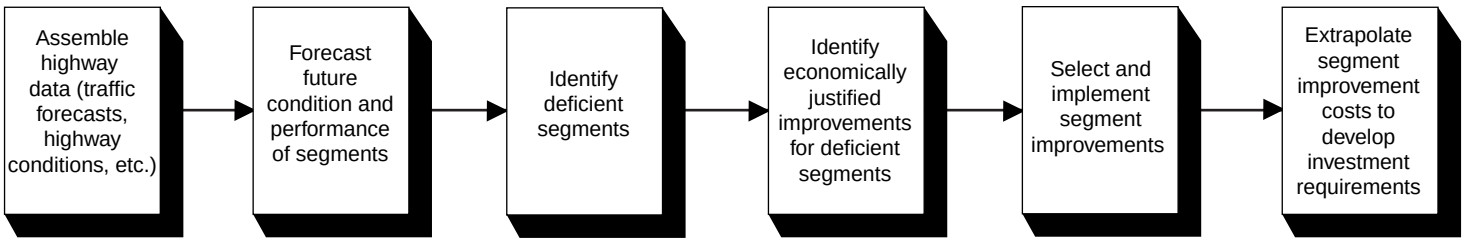
benefits of making an improvement. FHWA obtains emissions data for several classes of vehicles from the Environmental Protection Agency (EPA). FHWA also obtains dollar estimates from the economic literature for the human health and property damages caused by specific pollutants.

The HERS Model Evaluates the Relative Benefits and Costs of Alternative Improvement Options

The HERS model simulates the effects of infrastructure improvements for the highways it models by comparing the relative benefits and costs associated with alternative improvement options.[4] The HERS model begins by assessing the current condition of the highway segments in the data sample. The model then projects the future condition and performance of the segments, based on expected changes in factors such as traffic, pavement condition, and average speed. Performance is measured in terms of highway congestion. The model makes its projections in four 5-year increments (funding periods), for a total of 20 years.

Figure 3 provides a simplified representation of the modeling process. The model compares each segment's future condition with FHWA criteria for highway deficiencies for factors such as pavement condition, congestion, and lane width. For each segment identified as deficient (not meeting the criteria), the model assesses the relative costs and benefits associated with alternative improvement options to determine whether improving the segment is economically justified. The options range from resurfacing the pavement to completely reconstructing the road and adding lanes.

Figure 3: Simplified Representation of the HERS Modeling Process



Source: FHWA.

[4] FHWA documented the model's specifications in its draft report entitled *Highway Economics Requirements System Technical Report* (U.S. Department of Transportation, Federal Highway Administration, 1999).

The HERS model calculates costs as the capital expenditures required to construct the improvement and calculates the benefits as reductions in factors like travel time, vehicle operating costs, and accidents over the lifetime of the improvement. For example, adding lanes in congested areas can be beneficial because the increased capacity can reduce travel times, and operating costs.[5] Future benefits are discounted to the present.[6] The HERS model selects for implementation those improvements that are economically justified, including those improvements for which the estimated benefits exceed the cost of constructing the improvement (positive net benefits). To estimate the investment requirements for the highways it models, the HERS model uses "expansion" factors to generalize segment improvement costs to the nine highway classes included in the model. The expansion factors enable the HERS model to relate information about the sampled segments to the highway classes they represent. Investment requirements for the combined highway classes are obtained by adding together the estimates for the nine different classes. Appendix II describes the structure of the HERS model.

The HERS Model Estimates Highway Investment Requirements for Several Different Scenarios

FHWA uses the HERS model to forecast the investment requirements for the highways represented in the model on the basis of several different scenarios. For example, under the "economic efficiency" scenario, the HERS model selects for implementation those improvements that have positive net benefits (benefits minus costs). The investment requirements under this scenario are about $48 billion per year from 1998 through 2017. Similarly, under the cost to "maintain current (pavement) conditions" scenario, the HERS model selects for implementation the least costly mix of improvements that would maintain average pavement conditions at 1997 levels over the forecast period. Under this scenario, the investment requirements are about $29 billion per year. In addition to these scenarios, FHWA estimates the investment requirements for maintaining current

[5] The HERS model also uses "price elasticity" to assess the behavioral response of drivers to changes in the cost of traveling on the highway. Price elasticity mitigates to some extent the beneficial aspect of making highway improvements. For example, because improving a segment lowers travel costs, some drivers may respond by driving more frequently. As a result, traffic on the improved segment may increase more quickly than anticipated, reducing the future benefits of the improvement.

[6] Discounting accounts for the fact that, in general, one dollar today is worth more than one dollar a year from now.

(1997) levels of travel time and vehicle user costs. See table 2 for the HERS estimates representing the different scenarios.

Table 2: The HERS Model's Estimates for Highways

Dollars in billions

Scenario	HERS forecast of annual costs
Economic efficiency	$47.9
Maintain current travel times	39.1
Maintain current vehicle user costs	31.1
Maintain current pavement conditions	29.4

Note: Dollars are 1997 dollars. These estimates reflect only the HERS portion of FHWA's estimates of highway investment requirements.

Source: FHWA's 1999 C&P Report.

The HERS Model Has Strengths and Limitations

The HERS model has several strengths that make it a unique and reasonable tool for estimating a general level of the nation's highway infrastructure requirements. A major strength of the model is its ability to assess the relative benefits and costs associated with alternative options for making improvements on the nation's highways. We found no other transportation model that could assess benefits and costs of alternative improvement options at the national level. In addition, FHWA has convened expert panels to assess the reasonableness of the HERS methodology and has made some changes to the model in response to recommendations from the panels. The model also has several limitations. First, it does not completely account for the interrelationships between all highways and different transportation modes, such as how traffic is redistributed as improvements are made. Second, it does not fully account for the uncertainties associated with its methods, data, and assumptions. Third, it relies on a computational "shortcut" to approximate the future lifetime benefits of an improvement, even though this is no longer necessary. Finally, it uses data that vary in quality. Although the net effect of the limitations on the HERS estimates cannot be determined, FHWA is taking steps to mitigate some of these limitations.

The HERS Model's Major Strength Is Its Application of Benefit-Cost Analyses in Assessing Highway Investments

The HERS model's major strength is its ability to assess the relative benefits and costs associated with potential improvements in the nation's highways. This is a significant improvement over FHWA's previous methods, which used engineering standards to identify deficiencies and select improvements without regard to economic merit. By contrast, the HERS model selects for implementation only those improvements that are economically justified. We found no model other than HERS that is capable of applying benefit-cost analyses in estimating investment requirements at a national level. For example, the World Bank's Highway Design and Maintenance Standards model is designed to be used at the project level. In addition, a model known as StratBENCOST uses benefit-cost analyses to evaluate state and local highway projects.[7]

Another strength of the HERS model is that FHWA has consulted with experts in order to assess the model's reasonableness and improve it. For example, in June 1999, FHWA convened an expert panel consisting of economists and engineers from the public and private sectors. This panel found that FHWA has strengthened the model over time and that the recent refinements have increased its applicability and credibility.

FHWA has also instituted several procedures to make the state-provided data for the HERS model as reasonable as possible. For example, FHWA periodically conducts workshops to inform state transportation officials about changes to the database used by the HERS model, and FHWA staff are available to conduct additional training at the states' request. In addition, FHWA recently completed reassessing its database needs to eliminate unnecessary data items and reduce the states' data collection burden. Changes as a result of this reassessment became effective in 1999, and the states will submit data reflecting these changes to FHWA in June 2000. As a result of the reassessment, FHWA identified the potential for reducing the number of sampled segments in the database to 80,000 from its current level of about 125,000.

The HERS Model Has Some Limitations

Although the HERS model is a reasonable tool, we noted that it has several limitations. First, because the model analyzes each highway segment independently rather than the entire transportation system (collectively

[7] StratBENCOST was developed by HLB Decision Economics, Inc. for the National Cooperative Highway Research Program.

referred to as a network), it cannot completely reflect changes occurring among all highways and modes in the transportation network at the same time. For example, the HERS model does not capture the effect on traffic levels of improving one highway segment while leaving neighboring segments unimproved. The HERS model incorporates information on how changes in costs to users of vehicles affect the demand for travel (via "price elasticity"). As a result, FHWA officials assume that the HERS model captures the net effect of all changes in the transportation network as well as the overall economy. However, we did not find consensus among the transportation modeling experts we interviewed that the HERS model completely captures the net effect of all changes in the network. The implication of this limitation is unclear—it may over- or under-estimate the effect of changes in traffic resulting from a highway improvement. Nonetheless, transportation modeling experts we talked to generally agree that explicitly modeling the entire transportation network is not possible with the current state of the art in modeling or available data.

Second, because the HERS model is not designed to completely quantify the uncertainties associated with its methods, assumptions, and data, the model cannot estimate the full range of uncertainties within which its estimates vary. As a result, the precision of the model's estimates is unknown. In making its estimates, the HERS model relies on a variety of estimating techniques and hundreds of variables, all of which are subject to some uncertainties. Executive Order 12893 states that federal agencies, in evaluating infrastructure investments, should address uncertainty when the amount and timing of important benefits and costs are uncertain. For its C&P Report, FHWA accounted for some uncertainties by conducting "sensitivity analyses" to measure how much the HERS estimates change when the value of certain key inputs or assumptions used in the model are changed. Nevertheless, the sensitivity analyses do not account for all the uncertainties in the model. We discussed this issue with one of the HERS model's developers, who indicated that, according to his understanding of the model, the uncertainty associated with the "single point" estimates could range up to plus or minus 30 percent. However, changing the model to fully account for uncertainties in its factors is not likely to be cost-effective because it could require extensive and expensive reprogramming.

Third, the HERS model uses a computational shortcut to approximate the lifetime benefits associated with an improvement. Benefits and costs should be measured over each improvement's full lifetime, 20 years or more. However, in its initial evaluation of whether to improve a highway segment, the HERS model calculates benefits, such as reductions in travel

time, only during the first 5-year period. To account for the benefits accruing after the first 5 years, FHWA developed a shortcut that essentially uses an estimate of the improvement's construction cost as a proxy for the improvement's remaining future benefits.[8] FHWA developed the shortcut several years ago, when limitations in computer processing power necessitated simplifying some of the calculations. Several of the transportation modeling experts we talked to question whether these costs are a reasonable approximation of future benefits. Ideally, the model should estimate the benefits associated with an improvement over its full lifetime, discounted to the present. FHWA officials acknowledged that the shortcut is a limitation that is no longer necessary given recent improvements in computer processing power.

Fourth, although FHWA has taken steps to ensure that the data used in the HERS model are reasonable, some of these data vary in quality. For example, the HERS model relies on emissions data that some members of FHWA's 1999 expert panel consider unrepresentative of actual conditions. To estimate the emissions associated with traffic on a given segment, the model uses information from EPA on emissions rates per vehicle type and speed. Vehicle emissions, however, may depend more on how the vehicle is driven than on the total miles driven. FHWA officials told us they recognize that the emissions data may not reflect actual conditions but included the data to approximate the environmental effect of highway travel. EPA is currently revising these emissions data.

In addition, we reported earlier that the pavement roughness data reported by the states to FHWA are not comparable, partly because the states use different devices to measure roughness.[9] The HERS model uses the roughness data in projecting the pavement condition of each segment. Moreover, some of the information used in the model is dated. For example, the pavement resurfacing costs used in the HERS model are based on 1988 data (adjusted for inflation from 1988 to 1997).

Finally, to project the future condition of the pavement, the HERS model uses information that does not fully capture the range of environmental

[8] With this shortcut, the HERS model assumes that the remaining future benefits of an improvement can be approximated by the costs that would be avoided by making the improvement in the current 5-year period. See appendix II for more information.

[9] *Transportation Infrastructure: Better Data Needed to Rate the Nation's Highway Conditions*, (GAO/RCED-99-264, September 27, 1999).

conditions affecting the nation's highways.[10] To account for the effect of climate on pavement condition, for instance, the model assumes all segments face freezing and thawing conditions. However, segments in warm and drier areas of the country rarely face freezing or thawing conditions, and FHWA officials acknowledged that the pavement information does not completely account for these conditions. Although the effect of the variability in the quality of the data has not been determined, it reduces confidence in the overall precision of the HERS estimates.

FHWA Plans to Improve the HERS Model

FHWA recognizes that the HERS model has some limitations and is taking steps to improve it. For example, FHWA officials said they plan to revise the emissions data used in the HERS model as soon as EPA finishes revising its emissions model. In addition, FHWA plans to update the pavement resurfacing costs, currently based on 1988 data, to represent 1998 or 1999 costs. FHWA also has contracted with one of the model's developers to incorporate varied pavement performance information based on different climate zones throughout the country instead of assuming one climate as is now done. FHWA officials also expressed interest in revising the model to eliminate the computational shortcut used to approximate benefits. They said that as of March 2000, FHWA has not yet contracted to make this improvement. Furthermore, beginning this fiscal year, they plan to modify the HERS model to incorporate the effects of user fees, such as motor fuel taxes, into the model's assessment of the benefits and costs of alternative highway improvements.

In addition, FHWA is currently developing a state-level "prototype" of the HERS model in order to provide the states with the ability to forecast state-level highway investment requirements. FHWA is incorporating into the model selected features from customized versions of the HERS model developed for transportation officials in Indiana and Oregon by a private contractor. After the development of the state-level prototype is complete, FHWA will provide the model to a limited number of states as part of a pilot program to determine the usefulness of the model for state-level highway planning.

[10] HERS uses a pavement deterioration "submodel" to forecast pavement condition. See appendix II.

HERS Estimates Can Be a Useful Tool to Aid Decisionmaking but Have Limits

HERS estimates are useful as a general guide for the investment requirements of the nine highway classes represented in the model. In addition, the HERS estimates developed for the "economic efficiency" scenario can be useful for assessing the relative requirements of the highway classes over time. Congressional and federal agency officials told us they use the estimates as an overall indicator of highway needs. However, the limitations and inherent uncertainties associated with making forecasts prevent these estimates from being a precise forecast of investment requirements. In addition, because the current version of the HERS model was designed to estimate investment requirements at the national level, the estimates derived from this model should not be used to project investment needs for particular highway projects. Finally, as presented in the 1999 C&P Report, the uncertainties associated with the HERS estimates are not highlighted, and the HERS estimates are combined with other estimates that are not based on an assessment of the relative benefits and costs of alternative improvement options.

HERS Estimates Are Useful as a General Guide for Investment Requirements

In general, the HERS estimates provide legislative and executive branch officials one source of information to use for decisionmaking. Legislative and executive branch officials told us that they use the estimates in the C&P Report to obtain general information on the nation's need for infrastructure investments. Legislative branch officials told us that HERS estimates are more useful than previous estimates that were based on engineering analyses alone. Furthermore, different groups may use the HERS estimates in funding debates. For example, according to an FHWA official, construction industry interests could use the higher investment scenario estimate to show legislators a need for a higher level of highway funding.

In addition to serving as a general guide, the HERS estimates for the economic efficiency scenario can be useful in assessing the relative investment requirements over time for the nine highway classes represented in the model. Adjusting for inflation and changes in the model's formulas, assumptions, and data between reports, the HERS estimates from different reports can be compared to assess whether investment requirements are increasing, decreasing, or remaining the same. For example, using data developed for the 1995 C&P Report and the current C&P Report, FHWA found that the average annual highway investment requirements increased slightly, from $46.1 billion to $47.9 billion (1997 dollars).

Although the HERS model provides a general estimate of the highway investment requirements, in our view it is important that the model not be used for other than its intended purpose. First, while some federal officials have expressed an interest in using the HERS model to determine which highway projects should receive funding, the current version of the HERS model was developed to estimate investment requirements nationwide. As a result, the estimated investment requirements generated by the HERS model should not be used for project-level estimates.

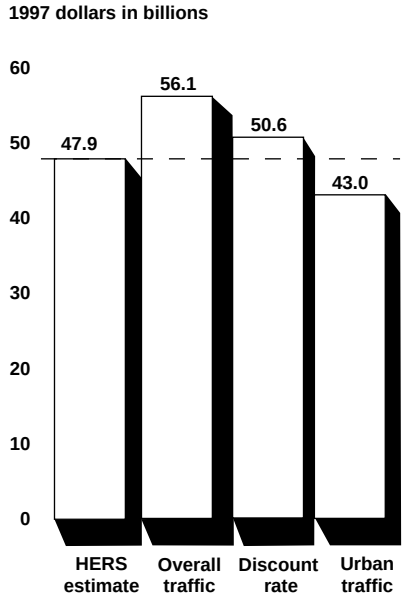
Second, federal decisionmakers we spoke with expressed an interest in retrospectively comparing actual highway investments by the states with those forecast by the HERS model. This comparison could be misleading because states may base their highway improvement decisions on criteria other than those used in the HERS model. For example, under the economic efficiency scenario, the model implements only those improvements that are economically justified (that have positive net benefits). However, some states may fund highway improvements that would not pass the same economic test. For example, states may improve a highway in an economically disadvantaged area in an attempt to foster economic development.

Third, although comparing the HERS estimates developed for the economic efficiency scenario in successive C&P Reports can be useful, making the same comparison using the HERS estimates for the maintain current conditions scenario could be misleading. Currently, the data used by the HERS model to establish the current condition of the highway system are updated every year. Because the HERS model uses the current condition of the highway system as a “baseline” in projecting future investment requirements, the HERS estimates for the maintain current conditions scenario can be influenced by the prior level of state spending. For example, if state spending on highway improvements declines relative to estimated investment requirements, the condition of the highway system might also decline. The subsequent HERS projection would be based on a new baseline, reflecting a decline in the condition of the highway system from the previous period. Moreover, the estimated investment requirements required to maintain the new current condition into the future would also decline since less investment would be required to maintain a more deteriorated condition. Such a decline in estimated investment requirements over time, however, might be misconstrued to indicate that the condition of the highway infrastructure is improving, when in fact it would indicate a decline in the baseline condition.

HERS Estimates Could be More Clearly Presented

As we discussed, the HERS model has several limitations that affect its ability to precisely estimate investment requirements. Furthermore, forecasting highway investments using computer models is by its nature an inexact science, and a model cannot capture all the complexities of transportation systems. Although FHWA conducted sensitivity analyses to quantify some of the uncertainties associated with the HERS estimates developed for its 1999 C&P Report, the report does not highlight the results of these analyses. For example, FHWA found that increasing its traffic growth assumption by 31.5 percent increased the HERS estimate by about 17 percent, from $47.9 billion to $56.1 billion (see fig. 4). The change in the assumption represented actual average annual growth from 1977 to 1997. However, because the C&P Report presents the HERS estimates as single-point estimates and the results from the sensitivity analyses are presented in a separate chapter later in the report, the range of uncertainties disclosed by the sensitivity analyses may not be evident to the reader. See appendix III for additional results from sensitivity analyses.

Figure 4: Sensitivity of HERS Estimate to Changes in Certain Assumptions



Source: FHWA.

Note: Dollars are 1997 dollars. Results are for the economic efficiency scenario, and represent the effect of changes in certain assumptions used in the HERS model. For example, the overall average annual growth in traffic in terms of vehicle miles traveled was increased by 31.5 percent, the discount

rate was lowered from 7 to 4 percent, and the average annual growth in traffic in the largest urbanized areas was decreased by 100 percent (to no growth). In terms of the latter assumption, about 29 percent of the estimate represents highway improvements in the largest urbanized areas.

In addition, when reporting on investment requirements for highways and bridges, the C&P Report did not clearly disclose that its estimates are only partially modeled using benefit-cost analyses. Specifically, only 51 percent of the reported investment requirement is based on the HERS model and its benefit-cost analyses. The other 49 percent, which consists of bridges and non-modeled factors such as the construction of new highways, is not based on the same methodology and thus has not been proven to be economically justified. As a result, the estimates are technically not comparable. In addition, FHWA views the highway investment requirements estimated outside the HERS model as less reliable. Although the C&P Report presents the estimates relating to highways and bridges separately, it combines the HERS-modeled estimates with the non-modeled estimates. Thus, as currently presented, it may not be evident to the reader that only a portion of the total highway investment requirements is based on benefit-cost analyses and as a result is economically justified. (See fig. 1 for an analysis of these estimates.)

Conclusions

In developing the HERS model to forecast the investment requirements for the nation's highways, FHWA has taken steps to enhance the model's integrity and rigor. Furthermore, because the model incorporates benefit-cost analyses in selecting potential highway improvement projects for inclusion in its estimates, it is a significant improvement over previous methods, which used engineering standards to identify highway deficiencies and estimated the cost of correcting these deficiencies without regard to economic merit. The HERS model selects those improvements that are economically justified and as a result provides the Congress with a more useful and realistic estimate. Although FHWA significantly improved upon the analytical rigor of previous methods by incorporating benefit-cost analyses, the HERS model has some limitations that affect the precision of its estimates.

While not all the limitations in the HERS model can be addressed because of the inherent complexities of modeling, FHWA is taking steps to improve the model. FHWA has expressed interest in changing the model to eliminate the shortcut for calculating an improvement's lifetime benefits but has not established a timeframe for this change. It is also planning to improve the model's information on pavement performance and cost. FHWA could present the model's estimates more effectively in its C&P

Report to help the report's readers be aware of the full extent of the caveats and uncertainties associated with the estimates. In particular, FHWA could highlight the uncertainties associated with the HERS estimates as indicated by its sensitivity analyses so that readers of the report do not believe the estimates are more precise than they actually are. Finally, FHWA's C&P Report generally presents an overall estimate of all highway investment requirements—combining the HERS estimates with other estimates that are developed using less rigorous methods. The report could highlight the difference between these estimates and note that FHWA has more confidence in the HERS-generated estimates.

Recommendations

In order to ensure that the HERS model achieves its objectives and that the limits of its estimates and the estimates presented in future conditions and performance reports are disclosed, we recommend that the Secretary of Transportation direct the Administrator of FHWA to

- establish a timeframe for revising the HERS model in order to account for the expected lifetime benefits that are associated with alternative highway improvement options;
- clarify, when presenting the HERS estimates, that there are uncertainties associated with the estimates and refer readers to the sensitivity analyses performed on the HERS model that illustrate these uncertainties; and
- explain in the report that one portion of the estimate for highway investment requirements is from the HERS model and is based on benefit-cost analyses and that the other portion was calculated using less reliable methods, as well as the percentage that each of these portions constitutes of the overall estimate.

Agency Comments and Our Evaluation

We provided a draft of this report to the Department of Transportation for review and comment. We met with Department officials, including the Team Leader for Highway Needs and Investment Planning in the Federal Highway Administration. These officials generally agreed with the findings and recommendations in this report. With regard to the recommendation to establish a timeframe for accounting in the model for the expected lifetime benefits of highway improvements, the Department plans to eliminate the computational shortcut it uses to approximate future lifetime benefits in time to prepare estimates for the C&P Report it will issue in 2003. In response to the recommendation to clarify the uncertainties associated

with HERS estimates, the Department plans to expand its use of uncertainty analysis beyond the analysis in the 1999 report for the C&P Report for 2001 in order to provide a more complete discussion of this issue. Finally, in response to the recommendation to distinguish between HERS model estimates and other less reliable estimates, the Department plans to clarify and enhance its discussion of these differences in the C&P Report for 2001, including a figure similar to our figure 1. In addition, the Department will work to expand the scope of HERS to consider more types of highway deficiencies and solutions to address them in order to reduce the percentage of estimates using these less reliable methods. The Department also provided technical and clarifying comments, which we incorporated into the report as appropriate.

We conducted our review from September 1999 through April 2000 in accordance with generally accepted government auditing standards.

We will send copies of this report to cognizant congressional committees; the Honorable Rodney E. Slater, Secretary of Transportation; and the Honorable Kenneth R. Wykle, Administrator, Federal Highway Administration.

If you or your staff have any questions about this report, please contact me at (202) 512-2834. Appendix IV lists key contacts and contributors to this report.

John H. Anderson, Jr.
Director, Transportation Issues

Scope and Methodology

To assess the reasonableness of the Highway Economic Requirements Systems (HERS) model's assumptions and data, and the usefulness of the model's results, we reviewed the Principles for Federal Infrastructure Investments (Executive Order 12893), the Federal Highway Administration's (FHWA) June 1999 expert panel's comments on the HERS model, and several FHWA reports and documents on the HERS model from 1994 through 1999.

In addition, we discussed the HERS methodology with FHWA economists and engineers and two of the FHWA contractors that helped develop the model. Moreover, we interviewed users of the HERS' results, including legislative and executive-branch officials, several members of the June 1999 HERS expert panel, and other transportation modeling experts (see list of names below). We attended the June 1999 expert panel meeting as well as an FHWA-sponsored outreach meeting on the *Conditions and Performance Report* (C&P Report) in November 1998. We used standard economic principles to evaluate the model's application of benefit-cost analyses and the key economic assumptions used in the model, and we asked FHWA to provide us with results for sensitivity analyses conducted using alternative values for price elasticity and the discount rate. In addition, we reviewed the methods used by other transportation models to assess highway investments.

To assess the reasonableness of the data used in the HERS model, we reviewed technical documents supporting the primary source of data—the Highway Performance Monitoring System (HPMS) database. In addition, we discussed the reliability of the HPMS data with FHWA officials, including the Chief of Highway Systems Performance. Because FHWA uses a "preprocessor" to convert the HPMS data into a HERS input data file, we reviewed the actions performed by the preprocessor to assess whether the values of the data elements in HPMS are consistent with those in the HERS input data file. To do this, we asked FHWA to provide us with basic statistics and frequencies for several key data elements in the HPMS database, both before and after the data were converted by the preprocessor. The data included average annual daily traffic, surface/pavement type, weighted design speed, peak and off-peak percent of vehicles with greater than four tires, speed limit, and widening feasibility. For most of the data items, the actions of the preprocessor produced at most minor changes in a very small percentage of the data elements. For the data items for which the actions of the preprocessor affected a larger percentage of the data elements, we asked FHWA to conduct a sensitivity analysis in order to assess the effect of changes in the

data items on the HERS estimates, using the maximum economic efficiency scenario. We found that changes in these data items did not markedly change the HERS estimates. See appendix III for the results of these sensitivity analyses.

In August 1987, we reported on our review of FHWA's HPMS sampling plan.[1] We found it to be statistically reasonable for selecting highway sections nationally. For our current effort, we reviewed FHWA's current guidance, which the states use to sample segments, and found it consistent with the guidance we reviewed in 1987.

The individuals we contacted include the following experts.

- Adjo Amekudzi, Assistant Professor of Civil and Environmental Engineering, Georgia Institute of Technology
- Kenneth D. Boyer, Professor of Economics, Department of Economics, Michigan State University
- Gregorio Camus, Programmer, Battelle Memorial Institute
- David J. Forkenbrock, Professor of Civil and Environmental Engineering and Chair, Public Policy Center, University of Iowa
- David Greene, Economist, Oak Ridge National Laboratory
- Chris Hoban, Principal Highway Engineer, The World Bank
- Douglass Lee, Principal Investigator, Volpe National Transportation Center
- Sue McNeil, Professor of Civil and Environmental Engineering, Carnegie Mellon University
- Mike Markow, Cambridge Systematics
- Michael Meyer, Professor and Chair, School of Civil and Environmental Engineering, Georgia Institute of Technology
- Carl L. Monismith, Robert Horonjeff Professor of Civil and Environmental Engineering and Professor in the Graduate School, University of California at Berkeley
- Arlee Reno, Engineer, Cambridge Systematics
- Herb Weinblatt, Principal, Cambridge Systematics

[1] *Highway Needs: An Evaluation of DOT's Process for Assessing the Nation's Highway Needs* (GAO/RCED-87-136).

Description of the HERS Model

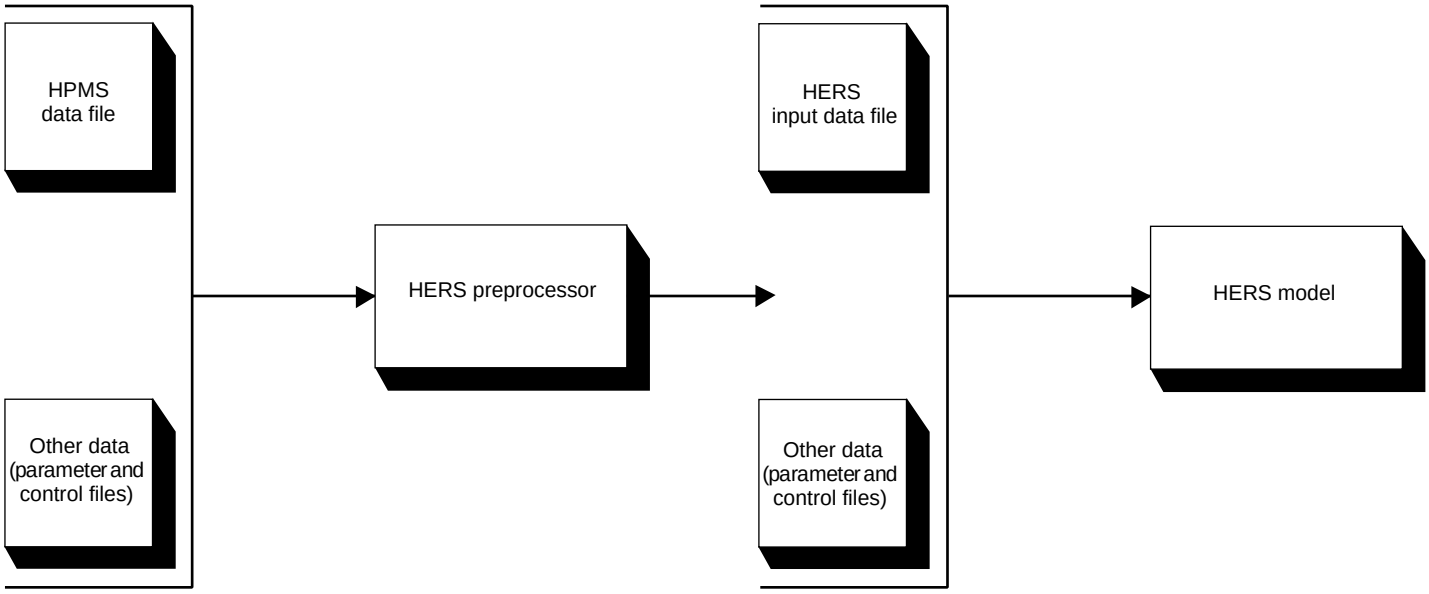
This appendix describes the basic structure of the HERS computer model. The HERS model simulates infrastructure improvement decisions for the highways it models by comparing the relative benefits and costs associated with alternative improvement options. In conducting its analysis, HERS uses an extensive set of data that are primarily collected and updated by the states and maintained by FHWA in the HPMS database. In addition, the HERS model consists of several submodels representing specific highway processes, including traffic growth, pavement wear, vehicle speed, accidents, and highway improvement costs. The analysis, which is based on the current condition of the highway system, is conducted over four 5-year periods, for a total of 20 years. Information from the submodels is used to identify deficient segments, evaluate alternative improvement options, and select and implement improvements. HERS uses benefit-cost ratios (benefits divided by costs) to evaluate and select improvements under several investment scenarios. The costs are the capital expenditures necessary to construct the improvement, and the benefits include reductions in users' operating costs, agency maintenance costs, and the "residual value" of an improvement. Residual value represents the benefits expected to accrue over the future life of an improvement beyond the analysis period used in the model. HERS uses a computational shortcut to estimate residual value.

HERS Uses an Extensive Data Set

HERS uses input data that are created from the HPMS database and several parameter and control files. HPMS consists of all the data collected and updated by the states on about 125,000 randomly selected highway segments across the United States, ranging in length from one block to 10 miles. The parameter and control files include information such as deficiency and design standards and basic instructions for the model. These data are converted to a HERS input file by a separate model called the "preprocessor," which aggregates all the data and performs various data manipulations. For example, the preprocessor assigns a speed limit of 75 mph to segments with no legally mandated maximum speed limit, and it converts the International Roughness Index data developed by the states to a "modified" Present Serviceability Rating (PSR) index.[1] See figure 5 for a representation of the process used to create the HERS input data.

[1] The HERS pavement deterioration submodel was not designed to use the International Roughness Index (IRI) so the preprocessor converts the IRI data to a "modified" PSR. The conversion is based on formulas developed by Al-Omari and Darter in *Relationships Between IRI and PSR,* Department of Civil Engineering, University of Illinois, 1992. Both IRI and PSR are measures of pavement condition, but IRI strictly measures surface roughness while PSR incorporates other types of pavement distress and may be based on professional judgement. IRI is measured by a moving vehicle using non-contact sensors such as lasers.

Figure 5: Schematic of Process Used to Create HERS Data



Source: FHWA data.

Developed in 1978 as a national highway transportation system database, HPMS is a nationwide inventory system that includes limited data on all public roads and more detailed data for a sample of highway segments representing nine different highway classes. The sampled data include information on highway capacity, average annual daily traffic, pavement roughness, and lane width. In addition to the sample data, the states are required to report certain basic inventory information for all public roads that are open to traffic, including an inventory of roads by highway class. The states also develop traffic forecasts for each segment. In addition, the HERS model uses "expansion" factors to extrapolate the cost estimates to the highway classes represented by the segments. The expansion factors are calculated by the HMPS software the states use to submit the data to FHWA.

Overall, the HPMS database includes nearly 100 variables. According to FHWA's Chief of Highway Systems Performance, the most accurate data in the HPMS database are variables that are directly measurable, such as the length of the highway section, number of lanes in the section, and speed limit. By contrast, the least accurate data are variables that are open to interpretation by state personnel, such as whether it is feasible to widen a

segment and the estimated percent of trucks traveling in peak and off-peak periods. For example, in assessing whether a segment can be widened, one state may view the potential high costs of widening as a detriment while another state may not. In addition, the states generally estimate the percent of trucks traveling during peak and off-peak periods from classification counts taken in a limited number of locations and of varying times and durations.

FHWA developed an HPMS field manual for the states to use in sampling highway segments and identifying which data items to collect and how to measure them. The sampling plan requires the states to select stratified random samples, where the strata represent different volume groups for different highway classes in the rural, small urban, and urbanized areas of each state. Estimates of average annual daily traffic are based on volume counts on each segment. Since each state selects its own sample, implementation of the sampling plan may vary.

FHWA has instituted some measures to improve the reasonableness of the HPMS data. FHWA provided the states with software they can use to assemble, edit, and submit their HPMS data. This software automatically performs checks for basic validity and missing data. Once the states edit their data, they run an expansion subroutine that places an expansion factor in each sample segment's record that is used to expand sample data to the full functional system. Once FHWA receives the data from the states, the data are passed through a software program that conducts basic logic checks, searches for anomalies, and reviews the distributions of sample-related items. FHWA staff review all items flagged during this check. FHWA works closely with the states to obtain answers to its questions concerning the HPMS data. Nonetheless, the potential for some variability in HPMS data remains because of potential differences in data collection techniques among the states.

In addition, from December 1996 through December 1998, FHWA reassessed its database needs in an effort to eliminate unnecessary data items and reduce the states' data collection burden.[2] As part of this effort, FHWA conducted public meetings with state officials to obtain their views on a future focus for the HPMS database. As a result of the reassessment, FHWA will make significant changes to the HPMS database. FHWA

[2] *Highway Performance Monitoring System Reassessment*, Final Report, Revised April 1999, FHWA-PL-99-001.

changed the HPMS field manual and software to guide the states in making needed changes. For example, FHWA decided to delete some data that the states have collected in the past but that it determined are no longer needed, such as the number of interchanges on segments. In addition, FHWA "collapsed" some data items into fewer categories to reduce state officials' time spent in collecting data. For example, the variable describing the surface or pavement type was reported in 15 categories, many of which were of little use, so these were reduced to 6 categories. In addition to these changes, the FHWA reassessment identified the potential for reducing the HPMS sample from over 125,000 segments to 80,000 segments to help reduce the states' data collection burden. The states began implementing the changes during their data collection efforts in 1999 and will report the revised data to FHWA by June 2000.

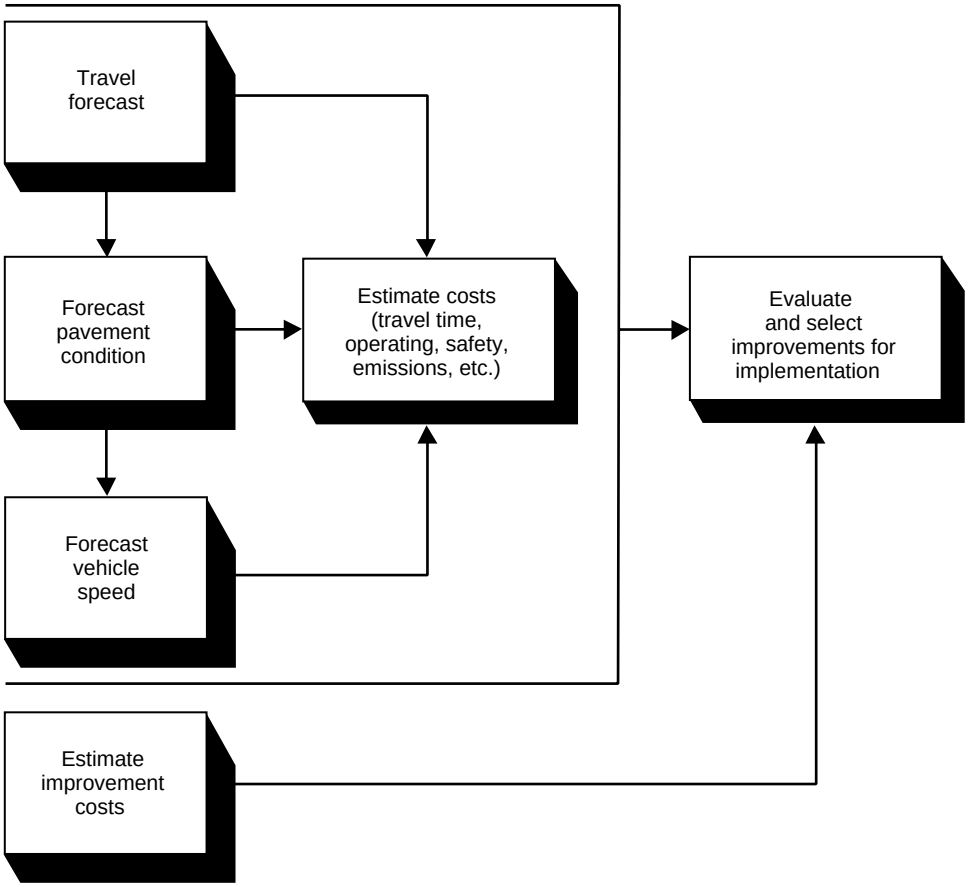
The HERS input data and additional parameter and control data are used by the HERS model to assess the relative benefits and costs of making highway improvements. The post-preprocessor parameter and control data include information that is independent of specific segments, such as travel-time costs, widening feasibility criteria, and the discount rate.

HERS' Submodels Represent Different Highway Processes

The HERS model consists of several submodels representing specific highway processes, such as traffic growth, pavement wear, operating costs, emissions costs, and highway improvement costs. The submodels are used to project the future condition and performance of the highway system with and without improvements (for example, the baseline) for each funding period and each segment.[3] In addition, the benefits associated with making highway improvements are estimated using several submodels linked together. Benefits are defined as reductions in user costs (travel time, safety, vehicle operating costs) and agency maintenance costs. In addition, the "residual value" of an improvement is considered to be a benefit. The implementation costs associated with making improvements are estimated using an improvement cost submodel. The information from the submodels is used to evaluate the benefits and costs of alternative improvement options, and select for implementation improvements that are economically justified. See figure 6 for a simplified representation of the structure of the HERS model.

[3] In some analyses, the baseline is a less "aggressive" improvement rather than no improvement at all.

Figure 6: Simplified Representation of the Structure of the HERS Model



Source: FHWA data.

The travel forecast submodel projects traffic growth on each segment, taking into account the price elasticity of travel demand. For each segment, the submodel uses information on the amount of current traffic (average annual daily traffic); initial price of travel (user costs, including operating, and travel time and safety costs); the state's traffic growth projection; and price elasticity to project future traffic volume in each funding period. Price elasticity measures the effect of changes in travel costs on travel demand.[4] Because there are no empirical estimates of elasticity with respect to total travel demand, FHWA uses a range of information on elasticities for the components that constitute total travel demand, including the price of fuel, vehicle wear, tolls, parking, and travel time. FHWA constructs a total demand elasticity, taking into account these effects as well as the share of each component in the total price of travel. For the 1999 C&P Report, the HERS model uses a price elasticity of –1.0 for the short run (over one funding period) and –1.6 for the long run (see app. III for sensitivity analysis results using –1.5 and –2.0 for the short- and long-run values, respectively). The output of the travel forecast submodel—adjusted traffic growth—serves as an input in the pavement deterioration, speed, and accident submodels. For example, increases in traffic growth can cause additional pavement wear and reduce average vehicle speed.

The pavement deterioration submodel is used to measure the effect of traffic and the environment on the future condition of the pavement. In general, this submodel uses adjusted traffic growth to project the effect of traffic on a segment's future pavement condition, in terms of its PSR. PSR is a measure of pavement condition, ranging from 0 (very poor or extremely deteriorated pavement) to 5.0 (very good or smooth pavement). In estimating future PSR, the submodel relies on equations that were derived in one climate zone ("wet/freeze").[5] To account for the effect of environment on pavement wear, the submodel assumes a minimum deterioration rate. In general, the minimum rate is a function of the time the pavement was last improved and its maximum life span (from 25 to 40 years, depending on the type of pavement). Output from the pavement

[4] More specifically, the price elasticity of demand is a measure of the percentage change in quantity demanded resulting from a percentage change in price. For example, suppose the price elasticity of demand for travel were estimated to be -0.8. Thus, if the price of travel increases by 1 percent, travel demand would be expected to fall by 0.8 percent.

[5] HERS uses road test equations developed by the American Association of State Highway Officials at a test site in Ottawa, Illinois. Because this site is located in a wet/freeze climate zone, the equations reflect the effect of only this one climate zone. The equations are being updated to incorporate the effect of more environmental factors.

deterioration submodel is used in the speed, user operating costs, and agency maintenance costs submodels. For example, increases in traffic growth can cause the pavement to deteriorate, further increasing vehicle operating costs. Moreover, worn pavement can reduce vehicle speeds, slow travel time, and increase a vehicle's fuel and maintenance costs.

The user costs submodel is used to assess the effect of future pavement condition and vehicle speed on travel-time costs, vehicle operating costs, and safety costs. Reductions in these costs brought about by highway improvements are considered "benefits." In measuring travel-time costs, the submodel considers both the time spent traveling by drivers for work purposes as well as by drivers for commuting, leisure, and other nonwork purposes. In the case of work-related trips, the submodel estimates travel time costs primarily on the basis of hourly compensation for each vehicle occupant. For the value of nonwork trips, the submodel uses 60 percent of each occupant's hourly compensation, excluding fringe benefits.

Vehicle operating costs are measured as a function of several factors, including pavement condition, highway grades and curves, and speed change cycles (for example, frequency of stopping). The submodel assesses the effect of these factors on various components of operating costs, including fuel and oil consumption, tire wear, vehicle maintenance, and vehicle depreciation. For example, tire wear and vehicle maintenance needs can increase as pavement condition worsens. In addition, steep grades and more frequent stopping can increase a vehicle's fuel and oil consumption.

The improvement cost submodel uses information on improvement type, highway class, and terrain type (flat, rolling, and mountainous) to project the capital costs required to construct an improvement. The capital costs represent the initial costs of constructing an improvement and depend on the type of improvement. In the case of improvements involving resurfacing or reconstructing pavement and widening lanes, improvement costs represent initial construction costs and expenditures required to obtain rights of way. For improvements that also involve an alignment, the HERS model estimates an additional cost that represents the cost required to improve a segment's substandard curves and grades. In addition to these improvements, the model estimates the cost of improving substandard conditions on urban freeways requiring reconstruction in certain circumstances (for example, when shoulders are unfinished). The improvements' costs are used in evaluating the benefits and costs of alternative improvement options.

The HERS model uses information from the submodels to identify deficient segments, evaluate the benefits and costs of alternative improvement options, and select and implement improvements. The model calculates benefit-cost ratios (total benefits divided by capital costs) to evaluate alternative improvement options for deficient segments. Improvements that meet specific investment criteria are selected and implemented. For example, under the economic efficiency scenario, the HERS model implements for each deficient segment the most "aggressive" improvement with a benefit-cost ratio greater than 1. In so doing, the model maximizes net benefits and, as a result, generates an economically efficient solution. "Aggressive" refers to the type of improvement that the model considers. For example, both the resurfacing and pavement reconstruction improvement types might improve the condition of a segment, but pavement reconstruction would be the more aggressive option because it requires more extensive construction. The HERS model extrapolates improvement costs using expansion factors in the HPMS database. The model combines the expanded improvement costs for all segments, and summarizes them by highway functional class.

HERS Uses Computational Shortcut to Estimate Lifetime Benefits of an Improvement

For certain portions of the analysis, the HERS model uses a "shortcut" to approximate the benefits that would accrue over the lifetime of an improvement. For example, for deficient segments, the model begins by conducting an analysis for one funding-period (5 years) to assess whether the segment should be improved in the current funding period or in some later period. A "no improvement" baseline is used to evaluate the timing of this investment decision. Because an improvement will continue to provide annual benefits after the first funding period is over, the model approximates these future benefits using information on the improvement's cost. More specifically, these future benefits are approximated by the improvement's construction cost minus the depreciation in the improvement after the first funding period, plus the cost savings from not having to maintain an unimproved segment in later funding periods. The total amount is referred to as the "residual value" of the improvement and is added to the other benefits associated with making an improvement. Ideally, in evaluating alternative improvement options, the HERS model should compare estimated implementation costs with the present value of benefits expected to occur in each future funding period. According to one of the model's developers, limitations in computer processing power when the HERS model was first developed prevented them from accounting for the full life cycle of benefits. As a result, they developed a computationally simpler algorithm to evaluate and select improvements. The developer also

indicated that computational time is no longer an issue because of the improvement in processing speeds.

Results of Sensitivity Analyses Using the HERS Model

Table 3 summarizes the results of sensitivity analyses FHWA performed on the HERS model. FHWA changed the value of one of the variables used in the HERS model by the amount indicated in the first column. The results of these changes on the HERS estimate are shown in columns 2 through 4.

Table 3: Percentage Change in HERS Estimates Resulting From Changes in Input Data

	Percent change in HERS estimate[b]		
Changes in variable[a]	**Rural**	**Urban**	**Overall**
Decreasing “D” by 1.4 (equivalent to 10 percent of its range from 0 to 14)	0.3	0.7	0.5
Increasing “D” by 1.4 (equivalent to 10 percent of its range from 0 to 14)	-0.1	-0.4	-0.3
Decreasing “SN” by 0.5 (equivalent to 10 percent of its range from 1 to 6)	6.6	4.4	5.2
Increasing “SN” by 0.5 (equivalent to 10 percent of its range from 1 to 6)	-1.5	-0.8	-1.1
Decreasing “Off-Peak Percent Trucks” by 20 percent	-1.2	-0.8	-0.9
Increasing “Off-Peak Percent Trucks” by 20 percent	1.1	0.4	0.7
Decreasing “Peak Percent Trucks” by 20 percent	-0.9	-0.4	-0.6
Increasing “Peak Percent Trucks” by 20 percent	0.9	0.3	0.6
Decreasing “Weighted Design Speed” by 10 percent	0.9	1.7	1.4
Increasing “Weighted Design Speed” by 10 percent	-0.6	-0.7	-0.6
Decreasing “Modified PSR” by 10 percent	6.8	10.4	9.0
Increasing “Modified PSR” by 10 percent	-4.8	-7.1	-6.2
Changing “Price Elasticity” from –1.0 to –1.5 for short run and from –1.6 to –2.0 for long run	9.2	3.1	5.5
Changing “Discount Rate” from 7 percent to 4 percent	5.4	5.8	5.6

Note: Sensitivity analyses based on HERS version 3.26D, used in developing the 1999 C&P Report. For all variables except price elasticity and discount rate, changes were made in the HERS preprocessor output data file. For price elasticity and discount rate, changes were made in the HERS parameter file.

[a] Variables are defined as follows:

D is the thickness (or depth) of rigid pavement on sampled roadway segments and *SN* is the structural number for flexible pavement on sampled roadway segments. HPMS contains the actual value when it is known. Otherwise, HPMS contains a typical value for the functional system and pavement type based on historical data or state practice. The HERS preprocessor assigns either slab thickness (D) or structural number (SN) to all paved sections for which SN or D was not supplied in the HPMS database. Depending on the information available, the assignment process may reference the section’s surface type; pavement section (if heavy, medium, or light); or traffic volume data.

Peak Percent Trucks and Off-Peak Percent Trucks is an estimate of trucks as a percentage of all traffic during peak or off-peak travel times. States generally estimate using a small number of classification count stations, comparing the sample section to similar segments elsewhere, and using local knowledge of travel patterns.

Weighted Design Speed is the speed for which the highway is designed, weighted by the length of the horizontal curves and tangents in a sample section. The HPMS database requires weighted design speed only for rural major collectors. For rural sections and some urban sections (interstates and other

freeways and expressways) without reported curves, the HERS preprocessor reads the weighted design speed from a lookup table (Appendix M in the HPMS Field Manual).

Modified PSR (Present Serviceability Rating) is a measure of the pavement condition of a sample section. For PSR, states assign values to the pavement condition of a segment using a scale from 0.0 (extremely deteriorated pavement) to 5.0 (new, or nearly new, superior pavement). Most states also provide information on pavement roughness in terms of the International Roughness Index (IRI). The HPMS database reports pavement condition in terms of the IRI for 70.5 percent of the segments and PSR for 84.7 percent of the segments. However, because HERS was not designed to use IRI data, the HERS preprocessor converts all IRI measurements to a "modified" PSR value. In cases where both IRI and PSR values are reported for a segment, the IRI value is converted to a "modified" PSR value, which replaces the original PSR value.

[b] Percent changes are based on HERS estimates of about $18.8 billion for Rural, $29.1 billion for Urban, and $47.9 billion for Overall (1997 dollars) calculated for the economic efficiency scenario. Rural is the total annual average improvement cost for rural interstates, other principal arterials, minor arterials, and major collectors. Urban is the total annual average improvement cost for urban interstates, other freeways and expressways, other principal arterials, minor arterials, and collectors. Overall is combined Rural and Urban.

Source: FHWA's Highway Economic Requirements System.

GAO Contacts and Staff Acknowledgments

GAO Contacts

John H. Anderson, Jr. (202) 512-2834

Katherine Siggerud (202) 512-2834

Staff Acknowledgments

In addition to those named above, Richard Calhoon, Catherine Colwell, Timothy J. Guinane, Mehrzad Nadji, Judy K. Pagano, Raymond Sendejas, and Phyllis F. Scheinberg made key contributions to this report.

Ordering Information

The first copy of each GAO report is free. Additional copies of reports are $2 each. A check or money order should be made out to the Superintendent of Documents. VISA and MasterCard credit cards are accepted, also.

Orders for 100 or more copies to be mailed to a single address are discounted 25 percent.

Orders by mail:
U.S. General Accounting Office
P.O. Box 37050
Washington, DC 20013

Orders by visiting:
Room 1100
700 4th St. NW (corner of 4th and G Sts. NW)
U.S. General Accounting Office
Washington, DC

Orders by phone:
(202) 512-6000
fax: (202) 512-6061
TDD (202) 512-2537

Each day, GAO issues a list of newly available reports and testimony. To receive facsimile copies of the daily list or any list from the past 30 days, please call (202) 512-6000 using a touchtone phone. A recorded menu will provide information on how to obtain these lists.

Orders by Internet:
For information on how to access GAO reports on the Internet, send an e-mail message with "info" in the body to:

info@www.gao.gov

or visit GAO's World Wide Web home page at:

http://www.gao.gov

To Report Fraud, Waste, or Abuse in Federal Programs

Contact one:

- **Web site: http://www.gao.gov/fraudnet/fraudnet.htm**
- **e-mail: fraudnet@gao.gov**
- **1-800-424-5454 (automated answering system)**

PRINTED ON RECYCLED PAPER

United States
General Accounting Office
Washington, D.C. 20548-0001

Official Business
Penalty for Private Use $300

Address Correction Requested

Bulk Rate
Postage & Fees Paid
GAO
Permit No. GI00