APPENDIX A
Highway Investment Analysis Methodology

Highway Investment Analysis Methodology

Investments in highway resurfacing and reconstruction and in highway and bridge capacity expansion are modeled using the Highway Economic Requirements System (HERS), which has been used since the publication of the 1995 C&P Report. This appendix describes the basic HERS methodology and approach, and details the model features that have changed significantly from those used for the 2015 C&P Report.

Highway Economic Requirements System

HERS begins the investment analysis process 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 5-year 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 (a measure of congestion), lane width, right shoulder width, shoulder type, horizontal alignment (curves), and vertical alignment (grades).

After HERS determines that a section's pavement or capacity is deficient, it identifies potential improvements to correct some or all of the section's deficient characteristics. The HERS model evaluates seven kinds of improvements: resurfacing, resurfacing with shoulder improvements, resurfacing with widened lanes (i.e., minor widening), resurfacing with added lanes (i.e., major widening), reconstruction, reconstruction with widened lanes, and reconstruction with added lanes. For reconstruction projects, the model allows for upgrades of low-grade surface types when warranted by sufficient traffic volumes. For improvements that add travel lanes, HERS further distinguishes between two capacity additions: those that can be made at "normal cost" and those on sections where obstacles to widening are present, making capacity additions feasible only at "high cost." HERS might also evaluate alignment adjustments to improve curves, grades, or both.

When evaluating which potential improvement, if any, should be implemented on a particular highway section, HERS employs incremental benefit-cost analysis. This analysis compares the benefits and costs of a candidate improvement with those of a less aggressive alternative—for example, reconstructing and adding lanes to a section could be compared with reconstruction alone. HERS defines benefits as reductions in direct highway user costs, agency costs, and societal costs. Highway user benefits include reductions in travel time costs, crash costs, and vehicle operating costs (e.g., fuel, oil, and maintenance costs); agency benefits include reduced routine maintenance costs (plus the residual value of projects with longer expected service lives than the alternative); societal benefits include reduced vehicle emissions. Increases in any of these costs resulting from a highway improvement (such as higher emissions rates at high speeds or the increased delay associated with a work zone) would be factored into the analysis as a negative benefit ("disbenefit").

Dividing these improvement benefits by the capital costs associated with implementing the improvement results in a benefit-cost ratio (BCR) that is used to rank potential projects on different highway sections. HERS implements improvements in order of BCR, with the improvement having the highest BCR implemented first. Thus, as each additional project is implemented, the marginal BCR declines, resulting in a decline in the average BCR for all implemented projects. However, total net benefits continue to increase as additional projects are implemented, until the point at which the marginal BCR falls below 1.0 (i.e., costs exceed benefits). Investment beyond this point is not economically justified because a decline in total net benefits would result.

Because HERS analyzes each highway section independently rather than the entire transportation system, it cannot fully evaluate the network effects of individual highway improvements. Although efforts have been made to account indirectly for some network effects, HERS is fundamentally reliant on its primary data source—the national sample of independent highway sections contained in HPMS. Fully recognizing all network effects would require developing significant new data sources and analytical techniques.

HERS Improvement Costs

For the 2004 C&P Report, significant changes were made to the structure of the HERS improvement cost matrix, the assumed unit costs in that matrix, and the manner in which those values were applied. The improved cost updates reflected in the 2004 C&P Report were based on highway project data from six States. The 2004 update disaggregated the improvement cost values in urban areas by functional class and by urbanized area size. Three population groupings were used: small urban (populations of 5,000 to 49,999), small urbanized (populations of 50,000 to 200,000), and large urbanized (populations of more than 200,000).

For the 2006 C&P Report, additional project cost data were collected for large urbanized areas, rural mountainous regions, and high-cost capacity improvements. These data were used to update the HERS improvement cost matrix, which was also modified to include a new category for major urbanized areas with populations of more than 1 million. The HERS improvement cost matrix was adjusted further for the 2008 C&P Report based on additional analysis of the data previously collected.

Exhibit A-1 identifies the costs per lane mile assumed by HERS for different types of capital improvements. For rural areas, separate cost values are applied by terrain type and functional class, while costs are broken down for urban areas by population area size and type of highway. These costs are intended to reflect the typical values for these types of projects in 2014, and thus do not reflect the large variation in cost among projects of the same type, even in a given year. Such variation, which is evident in the project-level data on which these typical values are based, is attributable to several location-specific factors. For example, the costs assumed for highway widening projects are predicated on each section's having several bridges typical for the section's length, but in reality some sections will have more bridges than other sections of equal length, which adds to costs. Among other factors that could make costs unusually high are complicated interchanges, major environmental issues, and other extreme engineering issues.

The values shown in *Exhibit A-1* for adding a lane at "normal cost" reflect costs of projects for which sufficient right-of-way is available or readily obtained to accommodate additional lanes. The values for adding lane equivalents at "high cost" are intended to reflect situations in which conventional widening is infeasible and alternative approaches are required to add capacity to a given corridor. Such alternatives include the construction of parallel facilities, double decking, tunneling, or the purchase of extremely expensive right-of-way. HERS models these lane equivalents as though they are part of existing highways, but some of this capacity could be from new highways or other modes of transportation.

Exhibit A-1: Typical Costs per Lane Mile Assumed in HERS by Type of Improvement

Category	Typical Costs (Thousands of 2014 Dollars per Lane Mile)								
	Re-construct and Widen Lane	Re-construct Existing Lane	Resurface and Widen Lane	Resurface Existing Lane	Improve Shoulder	Add Lane, Normal Cost	Add Lane, Equivalent High Cost	New Alignment, Normal	New Alignment, High
Rural									
Interstate									
Flat	$1,993	$1,302	$1,128	$462	$86	$2,561	$3,551	$3,551	$3,551
Rolling	$2,234	$1,335	$1,298	$492	$142	$2,777	$4,493	$4,493	$4,493
Mountainous	$4,235	$2,924	$2,151	$728	$297	$8,646	$10,121	$10,121	$10,121
Other Principal Arterial									
Flat	$1,556	$1,042	$941	$371	$57	$2,052	$2,937	$2,937	$2,937
Rolling	$1,757	$1,071	$1,069	$413	$96	$2,197	$3,546	$3,546	$3,546
Mountainous	$3,412	$2,411	$2,072	$583	$126	$7,756	$8,931	$8,931	$8,931
Minor Arterial									
Flat	$1,423	$915	$877	$329	$54	$1,865	$2,618	$2,618	$2,618
Rolling	$1,718	$1,013	$1,091	$354	$99	$2,138	$3,372	$3,372	$3,372
Mountainous	$2,854	$1,871	$2,072	$486	$224	$6,547	$7,857	$7,857	$7,857
Major Collector									
Flat	$1,499	$969	$905	$336	$69	$1,937	$2,617	$2,617	$2,617
Rolling	$1,640	$985	$1,018	$356	$93	$1,979	$3,220	$3,220	$3,220
Mountainous	$2,489	$1,541	$1,482	$486	$143	$4,191	$5,474	$5,474	$5,474
Urban									
Freeway/Expressway/Interstate									
Small Urban	$3,356	$2,324	$2,645	$564	$103	$4,211	$13,784	$5,675	$19,373
Small Urbanized	$3,608	$2,344	$2,736	$667	$137	$4,601	$15,117	$7,649	$26,114
Large Urbanized	$5,754	$3,837	$4,238	$895	$517	$7,700	$25,826	$11,220	$38,303
Major Urbanized	$11,509	$7,675	$8,224	$1,483	$1,034	$15,400	$64,219	$22,440	$85,845
Other Principal Arterial									
Small Urban	$2,925	$1,974	$2,420	$473	$105	$3,579	$11,691	$4,474	$15,270
Small Urbanized	$3,130	$1,998	$2,530	$559	$140	$3,878	$12,715	$5,520	$18,841
Large Urbanized	$4,471	$2,929	$3,702	$703	$451	$5,675	$18,961	$7,577	$25,864
Major Urbanized	$8,942	$5,857	$7,405	$1,135	$902	$11,350	$43,997	$15,154	$65,597
Minor Arterial/Collector									
Small Urban	$2,155	$1,491	$1,831	$346	$76	$2,643	$8,562	$3,228	$11,019
Small Urbanized	$2,258	$1,508	$1,848	$394	$93	$2,785	$9,050	$3,961	$13,520
Large Urbanized	$3,040	$2,017	$2,527	$483	$253	$3,861	$12,820	$5,155	$17,594
Major Urbanized	$6,080	$4,033	$3,822	$804	$507	$7,722	$43,997	$10,310	$54,445

Source: Highway Economic Requirements System.

Pavement Condition Modeling

The version of HERS used for this report incorporates a revision to the modeled relationship between pavement roughness and average speed. In the previous model, pavement roughness causes drivers to slow down only when it reaches a level of roughness found extremely rarely on U.S. highways (International Roughness Index (IRI) > ~380 in./mi.). This relationship, taken from the World Bank's HDM-4 model, was based mainly on studies from low-income countries that are dated and for which documentation is unavailable in some cases. Yu and Lu (2014) observed that relevant data on the roughness-speed relationship that could be generalized to the

United States is scant.[1] In their own study using data from California highways, they found that the average free-flow speed decreases 0.0083 mph with every 1 in/mi increase in roughness. In incorporating this finding into HERS, it has been assumed that pavement roughness has no impact on speed at roughness levels below IRI values of 157 in./mi. This threshold value is taken from the economic evaluation manual of the New Zealand Transport Agency, which advises users to assume zero impacts of pavement roughness on vehicle running costs and rider comfort for roughness levels below 2.5 m/km (=157 in./mi.).[2]

Valuation of Travel Time Savings

As indicated in Appendix A of the 2015 C&P Report, the values of travel time used in HERS were comprehensively updated to support the economic analyses of alternative highway investment levels presented in the main chapters of that report. The primary objectives of that update were to:

- Identify reliable, recent sources of information on major components of the values of travel time, including hourly values of vehicle drivers' and other occupants' time, vehicle occupancy, and the distribution of vehicle use by travel purpose.
- Expand HERS' previous estimates of the hourly value and amount of work-related business travel using light-duty passenger vehicles (automobiles and light trucks), which previously included only work-related travel in household vehicles, including corporate and government fleets, rental vehicles, emergency vehicles (police and fire), and taxi service.
- Distinguish between hourly values of travel time for buses and those for three- or four-axle single-unit trucks, which were previously combined into a single vehicle class in HERS.
- Ensure that the values of travel time for vehicle occupants used in HERS were consistent with DOT's official guidance on valuing travel time savings.

No important sources of new information on these issues since the previous C&P Report could be identified, so the adjustments to the values of travel time reported in this edition were limited to minor changes and technical corrections to the previous values. In addition, the values used in the current (23rd) edition of the C&P Report were converted from constant 2012 dollars, which were used in the previous report, to constant 2014 dollars, to make them consistent with other economic values used in the analyses described previously in this report.

Changes to key inputs used to construct the values of time reported in *Exhibit A-2*, corrections to the calculations used to construct the table entries, and their effects on the entries in the table include the following:

- A small fraction of use of rental cars (HERS VT1 and VT2) and light-duty trucks (VT3) was reassigned from personal to business travel to reflect households' use of rental vehicles. Previously, all household use of rental vehicles was assumed to be for personal travel; this revision assumes instead that household use of rental vehicles is divided between business and personal travel in the same proportion as is use of household-owned vehicles. Because business travel is assumed to be valued at a higher hourly rate than personal travel, this change slightly increases the average values of travel time per vehicle hour for HERS VT1, VT2, and VT3.

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[1] Yu, B, and Lu, Q. 2014, Empirical model of roughness effect on speed. International Journal of Pavement Engineering, vol. 15, no. 4, pp. 345-351.

[2] New Zealand Transport Agency 2016, Economic Evaluation Manual, First Edition, Amendment 1. Available at: http://www.nzta.govt.nz/assets/resources/economic-evaluation-manual/economic-evaluation-manual/docs/eem-manual-2016.pdf.

- Travel using light-duty trucks—including vans, pickups, and SUVs—owned by businesses but stored at the private residences of business owners or employees, as reported in the 2002 Vehicle Inventory and Use Survey, was accounted for separately. Use of these vehicles was previously assumed to be included in travel by household members reported in 2009 National Household Travel Survey (NHTS), but the extent to which this assumption was correct was unknown. The model has been updated to allow for the presence of additional passengers when these vehicles are used for business travel. This change increases the estimated average occupancy of HERS VT3 (4-tire trucks) slightly, which increases the value of travel time per vehicle hour for HERS VT3 slightly.
- Business travel using urban public transit and intercity bus services, as reported in the 2009 NHTS, was accounted for and valued separately. Previously, all passengers traveling on public transit and intercity buses were assumed to be engaged in personal travel. Because business travel is assumed to be valued at a higher hourly rate than personal travel, this change slightly increases the average values of travel time per vehicle hour for HERS VT5a (3-4 Axle Single-Unit Trucks) and 5b (Buses).

Exhibit A-2 shows components of the hourly value of travel time for each HERS vehicle type, reports the overall average values of time per vehicle hour in 2014 dollars, and compares these with the 2012 values used in the 2015 C&P Report.

Exhibit A-2: Estimated 2014 Values of Travel Time by Vehicle Type

	VT1	VT2	VT3	VT4	VT5a	VT5b	VT6	VT7
2014 Travel Time Cost Element	**Small Auto**	**Medium Auto**	**4-Tire Truck**	**6-Tire Truck**	**3–4 Axle Truck**	**Bus**	**4-Axle Combination**	**5+-Axle Combination**
Business Travel								
Value of Time per Person Hour	$32.30	$31.74	$30.90	$27.40	$28.13	$25.73	$28.53	$28.53
Average Vehicle Occupancy	1.33	1.33	1.36	1.38	1.14	1.50	1.02	1.02
Total Hourly Value of Occupants' Time	$42.98	$42.11	$42.17	$37.79	$32.18	$38.59	$28.99	$28.99
Vehicle Capital Cost per Vehicle	N/A	N/A	N/A	$12.38	$19.71	$7.80	$15.62	$12.95
Inventory Value of Cargo	N/A	N/A	N/A	N/A	N/A	N/A	$0.10	$0.17
Value of Time per Vehicle Hour	$42.98	$42.11	$42.17	$50.17	$51.89	$46.40	$44.72	$42.11
Personal Travel								
Value of Time per Person Hour	$12.53	$12.53	$12.53	N/A	N/A	$12.53	N/A	N/A
Average Vehicle Occupancy	1.57	1.76	1.64	N/A	N/A	12.64	N/A	N/A
Value of Time per Vehicle Hour	$19.74	$22.00	$20.55	N/A	N/A	$158.44	N/A	N/A
Share of Vehicle Use for Personal Travel	88.96%	90.32%	78.14%	N/A	N/A	89.90%	N/A	N/A
Average Values per Vehicle Hour								
2014	$22.31	$23.95	$25.27	$50.17	$51.89	$204.84	$44.72	$42.11
2012 (from 2015 C&P Report)	$21.43	$23.06	$24.58	$53.15	$54.34	$180.51	$44.37	$41.75

Source: DOT Revised Guidance on the Value of Travel Time in Economic Analysis (Revision 2 – 2015 Update) and internal DOT estimates.

Highway Operational Strategies

One of the key modifications to HERS, introduced in the 2004 C&P Report, was the ability to consider the impact of highway management and operational strategies, including Intelligent Transportation Systems (ITS), on highway system performance. This feature has been substantially updated in this report following review of literature on ITS impacts. Current and future investments in operations are modeled outside of HERS, but the impacts of these deployments affect the model's internal calculations, and thus also affect the capital improvements considered and implemented in HERS.

Among the many operational strategies available to highway agencies, HERS considers only certain types based on the availability of suitable data and empirical impact relationships. These strategies have been revised from the 2015 C&P Report after a literature review to update the impacts of operations strategies and to remove others. The 2015 C&P Report operations strategies that have changes in the method of application are:

- Ramp Metering is now modeled as an 8-percent increase in freeway base capacity; this value feeds directly into the freeway delay function. Compared to the previous method, the positive impact of ramp meters is now more modest.
- Integrated Corridor Management is now modeled as a 25-percent decrease in freeway base delay. This delay decrease is higher than the factor previously used, resulting in larger delay decrease.
- Traveler information and emergency vehicle signal preemption were removed from consideration due to questionable impact relationships from the literature.

The impacts of all other operations strategies remain the same. *Exhibit A-3* details the operational strategies deployed and the estimates of their impacts, which are based primarily on a review of the DOT ITS Benefits Database (https://www.itsbenefits.its.dot.gov/its/benecost.nsf/ByLink/BenefitsAbout).

Exhibit A-3: Impacts of Operations Strategies in HERS

Operations Strategy	Impact Category	Impact
Arterial Management		
Adaptive Signal Control	Delay	-25%
	Travel time	-12%
Automated Enforcement; Speed and Red Light Cameras	Total Crashes	-15%
Signal Timing Coordination	Delay	-20%
	Travel time	-10%
Freeway Management		
Ramp Metering	Mainline Capacity	6%
	Total Crashes	-30%
Road Weather Systems		
Anti-icing Technology	Total Crashes	-70%
RWIS and Other Weather Information	Total Crashes	-15%
Incident Management (Freeways Only)		
Incident Detection with Service Patrols	Incident Duration	-55%
Active Transportation and Demand Management Systems		
Dynamic Ramp Metering	Capacity	8%
Integrated Corridor Management Systems		
Smart Corridors Solutions (ASC, TSP, HOT/HOV Lanes, Ramp Metering)	Travel Time	-15%
	Total Crashes	-20%
	Total Delay	-25%

Source: Highway Economic Requirements System.

Examples of HERS Impact Estimates

HERS calculates the impacts of investments on speeds, operating costs, crash costs, and emissions. These calculations use a set of lookup tables and equations that vary by vehicle type and other variables, and are generally drawn from other published sources such as the Highway Capacity Manual and Highway Safety

Manual. More detailed information is available in the HERS Technical Report, which is currently being updated and will be made available online at (https://www.fhwa.dot.gov/policy/otps/).

Vehicle Operating Costs

Exhibit A-4 demonstrates the effects of pavement roughness on vehicle operating costs in the HERS model. Vehicle operating costs include fuel, oil, tires, maintenance and repair, and vehicle depreciation. For simplicity, figures are shown for only two vehicle types (small automobile and combination truck) over a range of speeds (20–70 mph), for three different pavement conditions (IRI 50, 95, 170) on level, straight pavement. As discussed in Chapter 6, ride quality changes from "good" to "fair" as IRI rises above 95 and then to "poor" for IRI above 170. HERS currently resets the IRI to 50 following a full reconstruction project.)

As *Exhibit A-4* shows, improvements to pavement condition reduce vehicle operating costs but the size of the impact varies. For example, for a small automobile traveling at 50 miles per hour on a level, straight road, estimated operating cost is 17 percent lower at an IRI of 50 rather than 170 (per-VMT cost of $0.291 vs. $0.351). For a combination truck under the same conditions, the estimated reduction in operating costs would be 16 percent. (Note that these results would differ for roads with curves or grades.)

Exhibit A-4: Example of Vehicle Operating Costs per VMT

International Roughness Index (IRI)	Vehicle Speed (miles per hour)					
	20	30	40	50	60	70
Small Automobiles						
50	$0.366	$0.305	$0.284	$0.291	$0.320	$0.365
95	$0.383	$0.322	$0.302	$0.311	$0.341	$0.390
170	$0.417	$0.357	$0.339	$0.351	$0.387	$0.442
Combination Trucks						
50	$1.220	$0.989	$0.884	$0.888	$0.990	$1.175
95	$1.258	$1.029	$0.929	$0.940	$1.050	$1.244
170	$1.341	$1.119	$1.030	$1.055	$1.184	$1.401

Source: Highway Economic Requirements System.

Emissions

Emissions are estimated using emission rates per VMT for three vehicle classes (four-tire autos and trucks; single-unit trucks; and combination trucks) and four highway types (rural highway with unrestricted access, rural highway with restricted access, urban highway with unrestricted access, and urban highway with restricted access). Highway improvement projects are modeled as affecting emissions through their influence on travel volumes and speeds. Emission costs are then monetized using data from EPA's MOVES model.

Exhibit A-5 provides an example of HERS' estimates of air pollution damage costs. It shows average air pollution costs per VMT at 5 mph intervals for each of HERS' three vehicle classes operating on rural highway sections with restricted access. The figures are an overall total for four types of emissions: CO, SOx, NOx, and PM. As shown, emission costs per VMT vary by vehicle type and speed but are substantially higher when vehicles are traveling at low speeds, such as during extreme congestion. For example, for four-tire vehicles, a decrease in speed from the 13–17 mph range to 3–7 mph increases the estimated emission cost by 91 percent (per VMT, from $0.0167 to $0.0319). For a combination truck making the same change in operating speeds, the increase in emission cost would be 70 percent. At any speed, the emissions cost per VMT is substantially higher for single-unit trucks than for four-tire vehicles, and still higher for combination trucks.

Exhibit A-5: Example of Emission Damage Costs ($ per Vehicle-Mile)

Speed	Four-Tire Vehicles	Single-Unit Trucks	Combination Trucks
< 3	$0.0515	$1.0493	$2.4214
3—7	$0.0319	$0.5331	$1.2262
8—12	$0.0214	$0.2958	$0.7699
13—17	$0.0167	$0.2271	$0.7215
18—22	$0.0140	$0.1924	$0.6659
23—27	$0.0135	$0.1693	$0.6262
28—32	$0.0139	$0.1605	$0.6098
33—37	$0.0156	$0.1437	$0.4813
38—42	$0.0169	$0.1372	$0.4603
43—47	$0.0177	$0.1316	$0.4438
48—52	$0.0177	$0.1257	$0.4045
53—57	$0.0169	$0.1201	$0.3580
58—62	$0.0164	$0.1119	$0.3385
63—67	$0.0166	$0.1086	$0.3528
68—72	$0.0172	$0.1060	$0.3640
>= 73	$0.0183	$0.1020	$0.3527

Source: Highway Economic Requirements System.

Safety

Crash rates are estimated in HERS using a set of empirically derived equations for six different types of roads: urban/rural freeways, urban/rural multi-lane roads, and urban/rural two-lane roads. Improvement projects modeled in HERS can affect estimated crashes through their influence on traffic volumes and other crash model parameters, such as grade, curvature, and the presence and dimensions of shoulders and medians.

Exhibit A-6 shows the calculations for rural multi-lane roads, which are based on a modified version of an equation developed by Wang, Hughes, and Stewart. (Jun Wang, Warren Hughes and Richard Stewart, *Safety Effects of Cross-Section Design of Rural Four-Lane Highways*, FHWA Report FHWA-RD-98-071, May 1998, Equation 6.)

Exhibit A-6: Safety Equation for Rural Multi-Lane Roads

$$CRASH = CRC \times AADT^{0.073} \times exp(0.131 \times RHRRML - 0.151 \times AC + 0.034 \times DDRML + 0.078 \times INTSPM - 0.572 \times RPA - 0.094 \times SHLDW - 0.003 \times MEDW + 0.429 \times PDEVEL)$$

where:

CRASH	crash rate per 100 million VMT
AADT	annual average daily traffic
CRC	crash rate coefficient for rural multilane roads (=165.5 in this case)
RHRRML	roadside hazard rating for rural multilane roads (=2.45)
AC	1 for sections with (full or partial) access control, 0 for other sections
DDRML	driveway density (per mile) for rural multilane roads (0.94 used for the 23rd C&P Report)
INTSPM	intersections per mile (maximum =10)
RPA	1 for rural principal arterials and rural Interstate, 0 for lower functional systems
SHLDW	right shoulder width, in feet (maximum = 12 feet)
MEDW	50 if positive barrier median, median width, in feet, otherwise (maximum = 50)
PDEVEL	probability that road is in area of dense development (=31% for undivided multi-lane and 9% for divided multi-lane)

Source: Highway Economic Requirements System.

Unquantified Costs and Benefits

Planning and Miscellaneous Agency Costs

The HERS model omits the costs that highway projects entail in public consultation and outreach. Also omitted are possible effects of highway projects on certain types of agency costs, such as those for overhead and highway law enforcement and safety; these effects defy quantitative generalizations, being quite context-specific. Even the direction of these effects could vary. For example, adding capacity to some highway corridors could reduce the incidence of aggressive driving, which can be engendered by frustration with stop-and-go traffic, which in turn could reduce the need for highway patrol presence. On other highway corridors, however, adding capacity could *increase* the need for highway patrol presence by making speeding more possible. For many items of overhead expense, one would expect the types of projects that HERS models to have only marginal impact if any: for example, simple resurfacing of pavement would generally not affect materially the costs of traffic control center operations.

Environmental Effects

Apart from changes to emissions of pollutants, HERS does not capture the environmental impacts of highway projects such as changes in noise levels, ecosystem disruption, or water runoff. The HPMS database on which HERS relies lacks the information that would be needed to model these effects, which do not readily lend themselves to quantitative, or even qualitative, generalizations. Projects often include elements to mitigate or remediate harm to the environment, such as noise walls; these are reflected in the HERS estimates of typical improvement costs. Although negative effects can remain, positive effects are also possible. For example, while increases in freeway traffic volume and speed may increase traffic noise levels, adding capacity to a severely congested urban arterial might reduce noise levels from congestion-related horn honking. Moreover, even with reasonable estimates of environmental impacts, translating these measures into impacts on well-being and monetary costs or benefits is generally quite challenging. How would an analyst value, for example, the loss of aesthetics from a row of trees being cut down to carve out additional lanes? The contingent valuation approach is standard for addressing such questions, but its validity is widely debated. For these various reasons, HERS limits its modeling of environmental impacts to the changes in pollution emissions.

Economic Effects

The savings in transportation costs that result from highways improvements produce a variety of economic adaptations that entail increased highway use ("induced travel"). Popular examples include changes to freight logistics, such as more frequent shipments to economize on inventory. As a generic allowance for the net benefits from such adaptations, HERS measures an "incremental consumer surplus," which could also be termed an induced travel benefit. Relative to the other user benefits that HERS measures—the savings in time and vehicle operating costs for existing travel—the induced travel benefit is quite small. However, it does not capture all the benefits from economic adaptations to highway improvements. Potential additional benefits can result from market catchment areas expanding after highways improve; this can increase both productivity (by facilitating competition) and the variety of goods and services that are available. FHWA continues to monitor and evaluate the growing body of research on these hard-to-measure benefits for possible future treatment within HERS.

Other Effects

HERS evaluates projects independently for a geographically scattered national sample of highway sections. Its assessment of national needs for highway investment will thus not capture benefits for which a network model would be required, such as the option value of additional alternative routes or travel routes becoming less circuitous. HERS also does not consider the effects of modeled highway improvements on non-motorized transportation. For motor vehicles, a possibly significant effect it does not capture is the increase in traveler comfort resulting from pavement improvements. Although research into how much travelers value this benefit is scant, this value could conceivably be significant compared to savings in vehicle operating costs from pavement improvements, which HERS does measure.

Future HERS Enhancements Currently Underway

As part of an ongoing program of model revisions and improvements, the matrix of typical costs per mile for the various types of highway capital improvements modeled in HERS, as reflected in *Exhibit A-1*, is currently being updated. As part of this effort, the matrix will be expanded to capture differences in costs associated with "typical reconstruction" versus "total reconstruction," which would involve complete reconstruction of the roadway starting at the subgrade. The current distinction between "normal cost" capacity expansion and "high cost" capacity expansion will be broadened to consider the impact on expansion costs resulting from different types of obstacles to widening that are now coded by the States in HPMS. Other aspects of this research effort include developing procedures for adjusting the cost matrix to remove costs associated with culverts and bridge replacements in conjunction with highway widening projects, in anticipation that future enhancements to the National Bridge Investment Analysis System will allow it to compute such needs more accurately than HERS can. Procedures also will be developed to facilitate analysis of the variable costs associated with different overlay depths.

Work is also underway to refine and update the new pavement performance equations recently introduced into HERS. These equations were based on an early version of the American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical Pavement Design Guide algorithms, some of which have subsequently been revised. This research is also intended to address certain anomalies encountered in translating the simplified mechanistic-empirical equations into the HERS framework.

FHWA has initiated a major effort to update the equations for predicting vehicle fuel economy and other vehicle operating costs currently included in HERS and in several other public and private-sector tools for highway benefit-cost analysis. The current HERS procedures are based on a 1982 study and are not considered adequately reflective of current vehicle technology and driving patterns. The new study builds on the Strategic Highway Research Program 2 Naturalistic Driving Study and the Road Information Database to develop driving cycles that will be used to model the relationship between vehicle speed and fuel consumption. The impacts of road curvature and pavement roughness on fuel consumption also will be explored. This project includes modeling the relationships among pavement roughness, speed, roadway characteristics, and vehicle operating costs such as repair and maintenance, tire wear, mileage-related vehicle depreciation, and oil consumption.

FHWA is engaged in research to update and refine the HERS valuation of travel time savings. The proliferation of tolled express lanes on U.S. highways has provided valuable new data for studies of motorist willingness to pay for travel time savings, and the evidence from these and other studies is being examined.