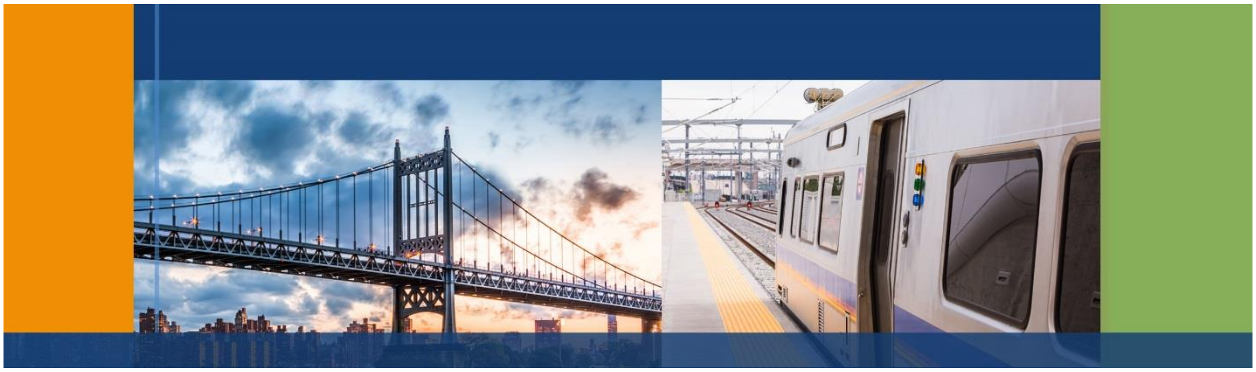

APPENDIX A: Highway Investment Analysis Methodology

Investments in highway resurfacing and reconstruction and in highway and bridge capacity expansion are modeled using the Highway Economic Requirements System (HERS), which was first used in the 1995 Conditions and Performance Report (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 23rd C&P Report. The most complete reference on the HERS model is the *Highway Economic Requirements System Technical Report*, which is currently being updated to align with HERS version 5.48 used for this edition of the C&P Report. The updated HERS Technical Report will be made available online.

Highway Economic Requirements System

The primary data source for the HERS model is information on a sample of approximately 130,000 representative highway segments collected from the States via the Highway Performance Monitoring System (HPMS). *Exhibit A-1* summarizes the types of input data used by HERS, the criteria HERS uses for rating a highway section as deficient, and the improvement options considered by HERS for remedying deficiencies.

For HPMS sample sections, HERS evaluates data on pavements, geometry, traffic volumes, and other characteristics. HERS then projects future conditions and performance of these sections by combining these data with many other model elements:

- Base-year estimates of prices and costs;
- Projections of future traffic growth on each section, fuel prices, and fuel efficiency;
- Physical relationships (equations) to predict pavement deterioration, travel delay, and fuel consumption rates by vehicle type;
- Behavioral relationships (equations) to predict, for example, travel demand induced by changes in travel time or vehicle operating cost; and
- Assumptions about future highway investment levels or policies (see Chapter 10).

HERS forecasts future conditions and performance across several funding periods—in this report, four consecutive 5-year periods. At the beginning of each period, the model checks for deficiencies in selected highway section characteristics. Of the characteristics on which HERS can rate a highway section as deficient (*Exhibit A-1*), only pavement roughness and traffic congestion are sufficient triggers for the model to evaluate improvement options. However, the evaluation of options to correct these triggering deficiencies also considers potential remedies for other deficiencies that may be present, such as improving narrow shoulders or realigning a section with excessive curvature.

Exhibit A-1 also presents the improvement options that HERS evaluates. For remedying pavement roughness, the options are reconstruction and resurfacing. The model selects reconstruction rather than resurfacing for a section when, at the start of the period: (a) roughness exceeds a certain engineering-based threshold, (b) the number of successive past resurfacings has already reached the limit of what is deemed feasible, or (c) the current surface type is too low-grade based on engineering-related criteria (e.g., an unpaved road that is sufficiently traveled and excessively rough). For traffic congestion, the main remedy in the model is to add lanes (with the number to be added determined by the model), although capacity can also be added through widening of lanes or shoulders. HERS does not consider types of targeted improvements that would primarily address safety issues, such as the addition of rumble strips, median treatments, or signalized intersection improvements. For most improvements of these types, evaluation would require road data beyond those HPMS currently provides.

Exhibit A-1 ■ HERS Model Overview

Category	HPMS Data Input Categories	Deficiency Criteria/ Improvement Triggers	Improvement Options
Pavement	▪ Surface & base types ▪ Roughness ▪ Distresses	▪ Surface type ▪ Roughness	▪ Reconstruction (w/option for surface type upgrade) ▪ Resurfacing (w/option for shoulder improvements)
Traffic/ Capacity	Traffic ▪ Average daily ▪ Vehicle type ▪ Peak period ▪ Directionality	▪ Congestion level (Volume/capacity)	▪ Adding lanes[1] ▪ Major widening[1]
Road Geometry	▪ Lanes ▪ Shoulders ▪ Medians ▪ Curves ▪ Grades ▪ Traffic control devices ▪ Intersections	▪ Lane width ▪ Right shoulder width ▪ Shoulder type ▪ Curves ▪ Grades	▪ Reduce curves[1] ▪ Reduce grades[1]
Other	▪ Speed limit ▪ Road work history ▪ Widening potential, etc. ▪ Miscellaneous		

[1] Improvement option only in combination with pavement preservation (resurfacing or reconstruction).

Source: HERS Technical Report.

HERS employs benefit-cost analysis to evaluate the potential improvements to a highway section; *Exhibit A-2* shows the categories of benefits and costs. Reductions in the costs of travel ("highway user benefits" are typically dominated by savings in the costs of travel time, but savings in vehicle operating costs can also contribute significantly. Although HERS captures the ancillary safety impacts of pavement and capacity improvements, it is not designed currently to capture impacts of targeted safety improvements; benefits from crash rate reductions thus contribute to the benefits that HERS estimates, but only modestly. The benefit-cost analysis in HERS also considers changes in vehicle emissions of pollutants, which are categorized as positive "benefits" if an improvement results in less pollution, or as "disbenefits" (negative benefits) if an improvement results in more pollution. The possibility of increased pollution arises because the improvements modeled in HERS typically worsen pollution by inducing more travel, which can outweigh the reductions in emissions that result from reduced traffic congestion (higher speeds). Whether positive or negative, the change in pollution costs is invariably a minor element in the HERS benefit-cost calculation.

Dividing these improvement benefits by the capital costs associated with implementing the improvement results in a benefit-cost ratio (BCR), which 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 marginal BCR falls below 1.0 (i.e., costs exceed benefits). Investment beyond this point is not justified economically because a decline in total net benefits would result.

Exhibit A-2 ■ Benefit-cost Analysis in HERS

Benefits & Costs Included	Category	Subcategory
User Benefits	Travel time savings	▪ Traveler time ▪ Time-related vehicle capital costs ▪ Time cost of freight in transit
	Vehicle operating cost savings	▪ Fuel ▪ Mileage-related depreciation ▪ Maintenance & repairs ▪ Tires ▪ Oil
	Crash risk reductions	▪ Fatalities ▪ Injuries ▪ Property damage
Agency Benefits	Road maintenance cost savings	▪ Adding lanes[1] ▪ Major widening[1]
	Project residual value[1]	
External Benefits/Costs	Changes in emissions of pollutants	▪ Carbon monoxide ▪ Volatile organic compounds ▪ Nitrogen oxides ▪ Sulphur dioxides ▪ Fine particulate matter
	Work-zone delays	
Capital costs	Costs of highway improvements	▪ Engineering ▪ Right-of-way ▪ Construction

[1] In comparison with an investment alternative that has a shorter expected service life; e.g., reconstruction vs. resurfacing.
Source: HERS Technical Report.

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.

Valuation of Travel Time Savings

With travel time savings typically the largest benefit to travelers from road improvements, the monetized values per unit of time saved are important parameters in any HERS analysis. *Exhibit A-3* 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 2016 dollars, and compares these with the 2014 values used in the 23rd C&P Report. For trucks, the values reflect not only the cost of the driver's time, but the benefits from freight arriving at its destination faster ("inventory value of cargo") and the opportunities for more intensive vehicle utilization when trips can be accomplished in less time ("vehicle capital cost"). The inventory value of the cargo component was minuscule in the case of combination trucks, and was not estimated for single unit trucks because of data issues and because some of these vehicles do not carry freight (e.g., garbage trucks).

Exhibit A-3 ■ Estimated 2016 Values of Travel Time by Vehicle Type

2016 Travel Time Cost Element	VT1 Small Auto	VT2 Medium Auto	VT3 4-Tire Truck	VT4 6-Tire Truck	VT5a 3–4 Axle Truck	VT5b Bus	VT6 4-Axle Combination	VT7 5+-Axle Combination
Business Travel								
Value of Time per Person Hour	$34.96	$34.31	$33.33	$29.75	$30.73	$27.56	$30.60	$30.60
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	$46.52	$45.52	$45.48	$41.03	$35.16	$41.33	$31.10	$31.10
Vehicle Capital Cost per Vehicle	N/A	N/A	N/A	$12.04	$20.51	$8.06	$16.25	$13.47
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	**$46.52**	**$45.52**	**$45.48**	**$53.07**	**$55.67**	**$49.39**	**$47.45**	**$44.73**
Share of Vehicle Use for Business Travel	11.0%	9.7%	21.9%	100.0%	100.0%	10.1%	100.0%	100.0%
Personal Travel								
Value of Time per Person Hour	$14.20	$14.20	$14.20	N/A	N/A	$14.20	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	**$22.36**	**$24.93**	**$23.28**	**N/A**	**N/A**	**$179.50**	**N/A**	**N/A**
Share of Vehicle Use for Personal Travel	89.0%	90.3%	78.1%	N/A	N/A	89.9%	N/A	N/A
Average Values per Vehicle Hour								
2016	**$25.03**	**$26.92**	**$28.13**	**$53.07**	**$55.67**	**$228.89**	**$47.45**	**$44.73**
2014 (from 23rd C&P Report)	$22.31	$23.95	$25.27	$50.17	$51.89	$204.84	$44.72	$42.11

Sources: U.S. DOT Revised Guidance on the Value of Travel Time in Economic Analysis (Revision 2 – 2016 Update) and internal DOT estimates.

Highway Operational Strategies

The Introduction to Part II discusses the allowance in HERS for future deployment of highway operational strategies. 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. *Exhibit A-4* lists 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-4 ■ 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.

Highway Economic Requirements System Improvement Costs

HERS contains estimates of typical cost per lane mile for different types of highway improvements. The estimates differ by highway functional class, type of improvement, and between rural and urban areas; additional breakdowns are included for rural locations by type of terrain and for urban locations by size of urbanized area. *Exhibit A-5* presents values for pavement improvements in rural areas used in the HERS runs that support this 24th C&P Report; *Exhibit A-6* contains comparable information for urban areas. *Exhibit A-7* and *Exhibit A-8* present values for capacity improvements in rural and urban areas, respectively.

For C&P Report editions from 2004 until the 23rd edition, cost estimates were based primarily on 2002 data with updates based on highway construction cost indices. Over time, however, the updates became less reliable because of limitations of the available indices. Whether costs of highway construction or other products are concerned, price-indexing over lengthy periods usually presents major challenges in adjusting for changes in product quality, product mix, or other confounding factors. For highway construction costs, an additional challenge arose when the Federal Highway Administration (FHWA) Bid Price Index was phased out (the data supplied by States became increasingly spotty) and replaced by the National Highway Construction Cost, which uses a proprietary database. This left ambiguous how to splice these two indices together to estimate cost changes between 2002 and 2005, which coincided with a period of great volatility in both indices. Moreover, even without this problem, the indices indicate only the overall change in costs; they do not pick up differences in the rates of cost change among improvements that differ by type and location characteristics.

Exhibit A-5 ■ Typical Rural Pavement Costs per Lane Mile Assumed in HERS by Type of Improvement

Category	Typical Costs (Thousands of 2016 Dollars per Lane Mile)						
	Resurfacing		Shoulder	Typical Reconstruction		Total Reconstruction	
	Resurface Existing Lane	Resurface and Widen Lane	Improve as Part of Resurfacing	Reconstruct Existing Lane	Reconstruct and Widen Lane	Reconstruct Existing Lane	Reconstruct and Widen Lane
Interstate							
Flat	$332	$979	$139	$1,160	$1,819	$1,604	$2,433
Rolling	$393	$1,157	$162	$1,372	$2,149	$1,890	$2,866
Mountainous	$500	$1,467	$201	$1,740	$2,722	$2,392	$3,623
Other Freeway and Expressway							
Flat	$312	$877	$120	$1,095	$1,670	$1,537	$2,273
Rolling	$368	$1,033	$139	$1,293	$1,970	$1,810	$2,675
Mountainous	$469	$1,311	$174	$1,640	$2,497	$2,290	$3,381
Other Principal Arterial							
Flat	$292	$798	$103	$1,030	$1,545	$1,472	$2,139
Rolling	$346	$942	$118	$1,217	$1,822	$1,732	$2,516
Mountainous	$440	$1,194	$148	$1,545	$2,310	$2,190	$3,180
Minor Arterial							
Flat	$266	$707	$85	$939	$1,386	$1,342	$1,933
Rolling	$314	$832	$98	$1,108	$1,634	$1,581	$2,275
Mountainous	$399	$1,054	$121	$1,405	$2,070	$1,997	$2,871
Major Collector							
Flat	$237	$618	$68	$840	$1,226	$1,212	$1,729
Rolling	$279	$728	$80	$992	$1,446	$1,426	$2,033
Mountainous	$355	$922	$99	$1,256	$1,830	$1,800	$2,565
Minor Collector							
Flat	$209	$548	$51	$752	$1,095	$1,102	$1,574
Rolling	$248	$645	$59	$887	$1,289	$1,296	$1,850
Mountainous	$314	$816	$73	$1,124	$1,631	$1,636	$2,334
Local							
Flat	$190	$500	$38	$688	$1,001	$1,029	$1,477
Rolling	$223	$588	$42	$810	$1,178	$1,211	$1,735
Mountainous	$281	$742	$52	$1,024	$1,487	$1,526	$2,185

Source: Highway Economic Requirements System.

For these reasons, FHWA funded a study to re-estimate typical construction costs with project-level data. The study identified 10 State departments of transportation that report pay item cost data at a geographic level—county or region—that is fine enough to allow demographics and terrain type to be characterized accurately for the local area for which the cost data were being reported. The pay item data reported by the State departments of transportation were mostly related to materials. Additional information was assembled from State departments of transportation websites, highway construction manuals, and commercial data sources, including labor and equipment costs associated with the work/pay items. The States included in the database collectively covered more than 700 counties across the United States. The assembled data represented, on average, 2 to 3 years of cost data from 2013 through 2015, and provided the basis for HERS cost estimates for 2014.

Exhibit A-6 ■ Typical Urban Pavement Costs per Lane Mile Assumed in HERS by Type of Improvement

Category	Typical Costs (Thousands of 2016 Dollars per Lane Mile)						
	Resurfacing		Shoulder	Typical Reconstruction		Total Reconstruction	
	Resurface Existing Lane	Resurface and Widen Lane	Improve as Part of Resurfacing	Reconstruct Existing Lane	Reconstruct and Widen Lane	Reconstruct Existing Lane	Reconstruct and Widen Lane
Interstate							
Small Urban	$581	$1,964	$405	$1,845	$3,244	$2,348	$3,972
Small Urbanized	$657	$2,239	$471	$2,107	$3,714	$2,725	$4,593
Large Urbanized	$787	$2,759	$624	$2,576	$4,587	$3,350	$5,667
Major Urbanized	$833	$3,028	$739	$2,789	$5,031	$3,604	$6,154
Other Freeway and Expressway							
Small Urban	$550	$1,758	$355	$1,740	$2,963	$2,257	$3,700
Small Urbanized	$622	$2,006	$416	$1,988	$3,394	$2,619	$4,281
Large Urbanized	$743	$2,465	$549	$2,426	$4,184	$3,216	$5,277
Major Urbanized	$789	$2,706	$652	$2,626	$4,588	$3,458	$5,729
Other Principal Arterial							
Small Urban	$520	$1,586	$309	$1,640	$2,720	$2,170	$3,466
Small Urbanized	$588	$1,808	$362	$1,872	$3,113	$2,515	$4,007
Large Urbanized	$703	$2,219	$477	$2,283	$3,832	$3,085	$4,936
Major Urbanized	$745	$2,432	$568	$2,468	$4,194	$3,317	$5,353
Minor Arterial							
Small Urban	$470	$1,352	$247	$1,470	$2,362	$1,974	$3,065
Small Urbanized	$532	$1,537	$286	$1,673	$2,694	$2,275	$3,527
Large Urbanized	$637	$1,882	$377	$2,035	$3,305	$2,779	$4,326
Major Urbanized	$675	$2,052	$442	$2,192	$3,597	$2,982	$4,674
Major Collector							
Small Urban	$410	$1,136	$208	$1,283	$2,017	$1,737	$2,642
Small Urbanized	$463	$1,290	$241	$1,460	$2,299	$1,995	$3,030
Large Urbanized	$544	$1,558	$316	$1,747	$2,779	$2,391	$3,653
Major Urbanized	$577	$1,702	$372	$1,881	$3,025	$2,560	$3,945
Minor Collector							
Small Urban	$367	$992	$154	$1,139	$1,770	$1,579	$2,385
Small Urbanized	$414	$1,121	$177	$1,290	$2,006	$1,800	$2,717
Large Urbanized	$488	$1,351	$231	$1,539	$2,414	$2,144	$3,253
Major Urbanized	$517	$1,464	$269	$1,650	$2,611	$2,290	$3,495
Local							
Small Urban	$337	$870	$118	$1,041	$1,578	$1,478	$2,184
Small Urbanized	$380	$985	$136	$1,178	$1,787	$1,677	$2,478
Large Urbanized	$447	$1,180	$178	$1,400	$2,139	$1,984	$2,947
Major Urbanized	$475	$1,278	$208	$1,500	$2,311	$2,114	$3,158

Source: Highway Economic Requirements System.

Exhibit A-7 ■ Typical Rural Capacity Costs per Lane Mile Assumed in HERS by Type of Improvement

Category	Typical Costs (Thousands of 2016 Dollars per Lane Mile)									
	Add Lane	Add Equivalent of One Lane of Capacity at High Cost Due to Obstacle to Widening of Type*:							New Construction	
	If No Obstacles (Normal Cost)	A	B	C	D	E	F	G	New Alignment (Normal)	New Alignment (High)
Interstate										
Flat	$1,604	$4,452	$5,685	$5,814	$9,621	$6,394	$4,288	$4,154	$5,205	$18,428
Rolling	$1,890	$5,777	$7,118	$6,650	$16,503	$7,793	$5,604	$5,421	$7,189	$25,450
Mountainous	$2,392	$9,486	$11,469	$9,971	$25,969	$12,931	$9,106	$8,706	$11,114	$39,343
Other Freeway and Expressway										
Flat	$1,537	$4,199	$5,381	$5,511	$9,221	$6,078	$4,025	$3,913	$4,917	$17,406
Rolling	$1,810	$5,495	$6,766	$6,359	$15,813	$7,396	$5,321	$5,163	$6,826	$24,163
Mountainous	$2,290	$8,933	$10,732	$9,454	$24,885	$12,037	$8,586	$8,236	$10,509	$37,201
Other Principal Arterial										
Flat	$1,472	$4,020	$5,157	$5,281	$8,823	$5,845	$3,849	$3,751	$4,712	$16,680
Rolling	$1,732	$5,265	$6,474	$6,121	$15,127	$7,063	$5,100	$4,959	$6,538	$23,145
Mountainous	$2,190	$8,427	$10,052	$8,983	$23,803	$11,211	$8,113	$7,808	$9,996	$35,389
Minor Arterial										
Flat	$1,342	$3,637	$4,728	$4,848	$8,296	$5,407	$3,455	$3,379	$4,306	$15,242
Rolling	$1,581	$4,812	$5,961	$5,660	$14,351	$6,514	$4,642	$4,525	$6,043	$21,395
Mountainous	$1,997	$7,655	$9,127	$8,246	$22,684	$10,156	$7,363	$7,102	$9,238	$32,703
Major Collector										
Flat	$1,212	$3,338	$4,393	$4,499	$7,769	$5,070	$3,161	$3,092	$4,004	$14,175
Rolling	$1,426	$4,408	$5,508	$5,247	$13,572	$6,032	$4,245	$4,141	$5,639	$19,962
Mountainous	$1,800	$6,915	$8,242	$7,541	$21,563	$9,149	$6,650	$6,428	$8,589	$30,405
Minor Collector										
Flat	$1,102	$3,006	$4,017	$4,117	$7,281	$4,685	$2,823	$2,772	$3,644	$12,900
Rolling	$1,296	$4,003	$5,049	$4,833	$12,824	$5,542	$3,836	$3,754	$5,189	$18,368
Mountainous	$1,636	$6,216	$7,406	$6,876	$20,456	$8,198	$5,969	$5,789	$7,890	$27,929
Local										
Flat	$1,029	$2,771	$3,738	$3,832	$6,869	$4,397	$2,587	$2,551	$3,372	$11,937
Rolling	$1,211	$3,715	$4,709	$4,536	$12,128	$5,170	$3,547	$3,483	$4,833	$17,110
Mountainous	$1,526	$5,674	$6,736	$6,369	$19,369	$7,419	$5,445	$5,303	$7,309	$25,873

* Obstacle widening types: A= Dense Development; B=Major Transportation Facilities; C=Other Public Facilities; D=Terrain Restrictions; E=Historic and Archaeological Sites; F=Environmentally Sensitive Areas; G=Parkland Areas

Source: Highway Economic Requirements System.

In addition to updating the cost estimates in HERS, the study also served to elaborate the model's treatment of obstacles to adding lanes. The HERS database includes separate estimates for the cost of adding lanes in the presence of obstacles such as dense development. In the past, the HPMS database indicated whether such obstacles were present on a sampled highway section; only recently was information added on the types of obstacles. In addition to dense development, these include major transportation facilities, other public facilities (e.g., schools, hospitals), terrain restrictions, historic and archaeological sites, environmentally sensitive areas, and parkland. As before, the estimates for high-cost lanes are differentiated by highway functional class and locational characteristics, as are normal-cost lanes. HERS also continues its practice of distinguishing low- and high-cost estimates for constructing highways on new alignments.

Exhibit A-8 ■ Typical Urban Capacity Costs per Lane Mile Assumed in HERS by Type of Improvement With and Without Obstacles to Widening

Category	Typical Costs (Thousands of 2016 Dollars per Lane Mile)									
	Add Lane	Add Equivalent of One Lane of Capacity at High Cost Due to Obstacle to Widening of Type*:							New Construction	
	If No Obstacles (Normal Cost)	A	B	C	D	E	F	G	New Alignment (Normal)	New Alignment (High)
Interstate										
Small Urban	$2,348	$5,772	$7,458	$7,516	$14,154	$8,145	$5,569	$5,376	$6,981	$24,713
Small Urbanized	$2,725	$7,502	$9,189	$8,879	$18,251	$10,068	$7,258	$7,022	$8,712	$30,842
Large Urbanized	$3,350	$9,349	$11,620	$10,321	$21,294	$13,001	$8,943	$8,511	$10,442	$36,968
Major Urbanized	$3,604	$11,027	$13,936	$12,650	$28,401	$16,485	$10,316	$9,696	$13,213	$46,775
Other Freeway and Expressway										
Small Urban	$2,257	$5,308	$6,925	$6,954	$13,594	$7,614	$5,089	$4,923	$6,558	$23,213
Small Urbanized	$2,619	$6,999	$8,619	$8,331	$17,524	$9,471	$6,747	$6,536	$8,228	$29,127
Large Urbanized	$3,216	$8,908	$11,031	$9,891	$20,442	$12,295	$8,517	$8,130	$9,935	$35,172
Major Urbanized	$3,458	$10,474	$13,173	$12,187	$27,264	$15,605	$9,788	$9,235	$12,546	$44,413
Other Principal Arterial										
Small Urban	$2,170	$4,954	$6,501	$6,502	$13,042	$7,192	$4,740	$4,588	$6,235	$22,072
Small Urbanized	$2,515	$6,586	$8,140	$7,873	$16,803	$8,966	$6,340	$6,145	$7,841	$27,756
Large Urbanized	$3,085	$8,530	$10,508	$9,525	$19,594	$11,657	$8,164	$7,815	$9,519	$33,697
Major Urbanized	$3,317	$10,022	$12,510	$11,825	$26,129	$14,829	$9,372	$8,878	$12,022	$42,556
Minor Arterial										
Small Urban	$1,974	$4,347	$5,822	$5,798	$12,270	$6,510	$4,116	$3,992	$5,655	$20,015
Small Urbanized	$2,275	$5,851	$7,338	$7,094	$15,863	$8,138	$5,594	$5,427	$7,149	$25,307
Large Urbanized	$2,779	$7,761	$9,602	$8,767	$18,569	$10,642	$7,404	$7,100	$8,756	$30,995
Major Urbanized	$2,982	$9,142	$11,444	$11,034	$24,917	$13,669	$8,502	$8,075	$11,100	$39,295
Major Collector										
Small Urban	$1,737	$3,806	$5,214	$5,159	$11,419	$5,903	$3,585	$3,472	$5,141	$18,200
Small Urbanized	$1,995	$5,148	$6,569	$6,346	$14,858	$7,344	$4,901	$4,748	$6,519	$23,079
Large Urbanized	$2,391	$6,881	$8,574	$7,898	$17,462	$9,498	$6,552	$6,286	$7,978	$28,243
Major Urbanized	$2,560	$8,229	$10,344	$10,211	$23,669	$12,473	$7,620	$7,248	$10,258	$36,312
Minor Collector										
Small Urban	$1,579	$3,320	$4,654	$4,576	$10,724	$5,337	$3,093	$3,004	$4,651	$16,465
Small Urbanized	$1,800	$4,545	$5,896	$5,698	$13,993	$6,642	$4,292	$4,164	$5,926	$20,977
Large Urbanized	$2,144	$6,184	$7,745	$7,211	$16,499	$8,565	$5,863	$5,640	$7,291	$25,809
Major Urbanized	$2,290	$7,410	$9,366	$9,481	$22,483	$11,422	$6,807	$6,494	$9,413	$33,323
Local										
Small Urban	$1,478	$2,964	$4,221	$4,123	$10,143	$4,898	$2,740	$2,669	$4,279	$15,146
Small Urbanized	$1,677	$4,107	$5,391	$5,215	$13,240	$6,109	$3,854	$3,747	$5,471	$19,368
Large Urbanized	$1,984	$5,668	$7,108	$6,706	$15,621	$7,834	$5,358	$5,173	$6,755	$23,911
Major Urbanized	$2,114	$6,681	$8,197	$8,792	$21,334	$10,061	$6,163	$5,982	$8,653	$30,632

* Obstacle widening types: A= Dense Development; B=Major Transportation Facilities; C=Other Public Facilities; D=Terrain Restrictions; E=Historic and Archaeological Sites; F=Environmentally Sensitive Areas; G=Parkland Areas

Source: Highway Economic Requirements System.

In the analysis conducted for this C&P Report edition, the update to the cost estimates reduced the estimates of investment needs in relation to the estimates that would have been obtained with the limited updating procedure used in the past several C&P Report editions. In the Maintain Conditions and Performance scenario, the reduction in average annual spending is from $118.0 billion to $98.0 billion, which equates to 16.1 percent; this simply indicates that the update had the overall effect of reducing the estimates of improvement costs. At the lower costs, however, more improvement projects pass the benefit-cost test; hence in the Improve Conditions and Performance scenario, the reduction in average annual spending is much smaller—from $167.5 billion to $165.9billion, or only 1.0 percent. Average annual investment in improvement types modeled in HERS is reduced from $68.7 billion to $54.7 billion (in the Maintain Conditions and Performance scenario) and from $92.8 billion to $91.7 billion (in the Improve Conditions and Performance scenario).[144]

Safety Costs

For each highway functional class, HERS estimates the average cost to society per vehicle crash from injuries and property damage. For injuries of varying severities, the estimated occurrence rate per crash is multiplied by the estimated cost per occurrence. The occurrence rates, which were last updated with 2007 data, indicate that few crashes produce fatalities. Across the highway functional classes, the numbers range from fewer than one death per 500 crashes on urban collectors to slightly over two deaths per 100 crashes on rural Interstates. The assumed cost per fatality equals the DOT estimate of the value of a statistical life in 2016, the base year for the modeling in this report. This value is a statistical summation of the benefit within the affected population of a reduction in crash fatality risk. Although few people would consider any amount of money to be adequate compensation for a person being seriously injured, much less killed, many can attach a value to changes in their risk of suffering an injury, even one that would be fatal, and indeed such valuations are implicit in everyday choices.[145]

The version of HERS used for this report incorporates new estimates of the cost per occurrence for nonfatal injuries and of the average per-crash property damage cost. The previous estimates captured only the costs from reported crashes. Although not a significant issue for crashes involving fatalities, many crashes involving lesser injuries or only property damage go unreported to authorities. The new estimates in the current version of HERS include costs from both reported and unreported crashes. The estimation procedures combine: (a) recent NHTSA estimates of property damage costs and of nonfatal injury rates by severity level with (b) DOT estimates for 2016 of the cost per nonfatal injury by severity level. For all nonfatal injuries, the inclusion of unreported occurrences increased the estimated cost per occurrence by 16.1 percent, and other modifications to the estimation procedures increased the estimate by a further 41.4 percent. For property damage, the new procedures increased the estimated cost per occurrence by 11.7 percent.

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/).

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[144] The reductions in the amount of investment programmed by HERS differ from the corresponding reductions in the scenario spending because of the application of the scaling procedures described in Chapter 10.

[145] For example, a traveler may face a choice between two travel options that are equivalent except that one carries a lower risk of fatal injury but costs more. If the additional cost is $1, then a traveler who selects the safer option is manifestly willing to pay at least $1 for the added safety—what economists call "revealed preference." Moreover, if the difference in risk is, say, one in a million, then a million travelers who select the safer option are collectively willing to pay at least $1 million for a risk reduction that statistically can be expected to save one of their lives. In this sense, the "value of a statistical life" among this population is at least $1 million.

Vehicle Operating Costs

Exhibit A-9 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-9* 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 $0.303 vs. $0.367). For a combination truck under the same conditions, the estimated reduction in operating costs would be 19 percent. (Note that these results would differ for roads with curves or grades.)

Exhibit A-9 ■ 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	$0.365	$0.318	$0.300	$0.303	$0.320	$0.351
95	$0.383	$0.337	$0.320	$0.324	$0.343	$0.378
170	$0.420	$0.374	$0.360	$0.367	$0.391	$0.433
Combination Trucks						
50	$0.936	$0.801	$0.750	$0.770	$0.853	$0.989
95	$0.980	$0.847	$0.801	$0.827	$0.918	$1.064
170	$1.074	$0.946	$0.911	$0.951	$1.062	$1.231

Source: Highway Economic Requirements System.

Emissions

For each of four types of emissions—CO, SOx, NOx, and PM—HERS estimates emission rates per VMT for three vehicle classes: four-tire vehicles; single-unit trucks; and combination trucks. The estimates are further differentiated by highway type according to location (rural vs. urban) and access arrangement (unrestricted vs. restricted). 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.

Unquantified Benefits

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.

Enhancements in Progress

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 American Transportation Research Institute Truck Data 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 nonfuel vehicle operating costs such as repair and maintenance, tire wear, mileage-related vehicle depreciation, and oil consumption. This effort is expected to be completed by the end of 2020.

Another research project underway will develop a Unified Pavement Distress Analysis and Prediction system (UPDAPS) for use in FHWA models. The project is specifically geared toward the pavement distress analysis requirements of HERS, the National Pavement Cost Model (NAPCOM), and the Pavement Health Track tool. The results of this project are expected to enable HERS to represent more accurately the relationship between pavement deterioration and factors such as traffic volumes and pavement characteristics.

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