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 by the Highway Economic Requirements System (HERS), which has been used since the 1995 C&P Report. This appendix describes the basic HERS methodology and approach in slightly more detail than is presented in Part II, including the treatment of intelligent transportation system (ITS) deployment and operations strategies, the allocation of investment across improvement types, and the calculation of the highway backlog. It also explores some of the improvements that have been made to the model since the 2006 C&P Report. These include the refinement of procedures that link investment levels to revenues and simulate the effect of universal congestion pricing, the extension of the analytical procedures to consider a broader range of operations strategies, and updates to the improvement costs matrix.

Highway Economic Requirements System

The HERS model initiates the investment analysis by evaluating the current state of the highway system using information on pavements, geometry, traffic volumes, vehicle mix, and other characteristics from the Highway Performance Monitoring System (HPMS) sample dataset. Using section-specific traffic growth projections, HERS forecasts future conditions and performance across several funding periods. As used in this report, the future analysis covers four consecutive 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, lane width, right shoulder width, shoulder type, horizontal alignment (curves), and vertical alignment (grades).

Once 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 improvements that add travel lanes, HERS further distinguishes between those that can be made at "normal cost" and those on sections with limited widening feasibility that could only be made at "high cost". HERS may also evaluate alignment improvements to improve curves, grades, or both.

> **Q&A**
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> **Where can I find more detailed technical information concerning the HERS model?**
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> The Federal Highway Administration has previously developed a Technical Report for the Highway Economic Requirements System. The most recent printed edition, dated December 2000, is based on HERS version 3.26, which was utilized in the development of the 1999 edition of the C&P report.
>
> The FHWA also has developed a modified version of HERS for use by States. This model, HERS-ST, builds on the primary HERS analytical engine, but adds a number of customized features to facilitate analysis on a section-by-section basis. HERS-ST version 4.0 is largely based on HERS version 4.097, which was utilized in developing the 2004 edition of the C&P report. "The Highway Economic Requirements System – State Version: Technical Report" is available online at http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersdoc.htm.

When evaluating which potential improvement, if any, should be implemented on a particular highway section, HERS employs incremental benefit-cost analysis. The HERS model 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; agency benefits include reduced maintenance costs (plus the residual value of projects with longer expected service lives than the alternative); and 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 or "disbenefit."

Dividing these improvement benefits by the capital costs associated with implementing the improvement results in a benefit-cost ratio that is used to rank potential projects on different highway sections. The HERS model implements improvements with the highest BCR 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, until the point where the marginal BCR falls below 1.0 (i.e., costs exceed benefits), total net benefits will continue to increase as additional projects are implemented. Investment beyond this point would not be economically justified because it would result in a decline in total net benefits.

Because the HERS model analyzes each highway segment independently, rather than the entire transportation system, it cannot fully evaluate the network effects of individual highway improvements. While efforts have been made to indirectly account for some network effects, HERS is fundamentally rooted to its primary data source, the national sample of independent highway sections contained in the HPMS. To fully recognize all network effects, it would be necessary to develop significant new data sources and analytical techniques. Part IV, Afterword, includes more discussion of this issue.

Allocating HERS Results Among Improvement Types

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

Highway Investment Backlog

To determine the action items for inclusion in the highway investment backlog, HERS evaluates the current state of each highway section before projecting the effects of future travel growth on congestion and pavement deterioration. Any potential improvement that would correct an existing pavement or capacity deficiency, and that has a BCR greater than or equal to 1.0, is considered part of the current highway investment backlog.

As noted in Chapter 7, the backlog estimate produced by HERS does not include either rural minor collectors or rural and urban local roads and streets (since HPMS does not contain sample section data for these functional systems), nor does it contain any estimate for system enhancements. The backlog for the bridge portion of system rehabilitation is modeled separately through the National Bridge Investment Analysis System (NBIAS), which is discussed in Appendix B.

Travel Demand Elasticity

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

> **Q&A**
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> **What are some examples of the types of behavior that the travel demand elasticity features in the HERS represent?**
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> If highway congestion worsens in an area, this increases travel time costs on the road network. In response, some highway users might shift their trips to mass transit or perhaps forgo some personal trips they might ordinarily make. For example, they might be more likely to combine multiple errands into a single trip because the time spent in traffic on every trip discourages them from making a trip unless it is absolutely necessary. Increases in fuel prices also increase the cost of driving, and would tend to have a similar impact.
>
> In the longer term, people might make additional adjustments to their lifestyles in response to changes in user costs that would impact their travel demand. For example, if travel time in an area is reduced substantially for an extended period of time, some people may make different choices about where to purchase a home. If congestion is reduced, purchasing a home far out in the suburbs might become more attractive, since commuters would be able to travel farther in a shorter period of time.

The basic principle behind demand elasticity is that, as the price of a product increases relative to the price of other products or services, consumers will be inclined to consume less of it. Conversely, if the price of a product decreases, consumers will be inclined to consume more of it, either in place of some other product or in addition to their current overall consumption. The travel demand elasticity procedures in HERS treat the cost of traveling a facility as its price. This means that the volume of traffic growth tends to be constrained when a highway becomes more congested and the cost of traveling it (i.e., travel time cost) increases, and that volume of travel tends to increase when lanes are added and highway user costs decrease.

As a result of travel demand elasticity, the overall level of highway investment has an impact on projected travel growth. For any highway investment scenario that results in a decrease in average highway user costs, the effective vehicle miles traveled (VMT) growth rate tends to be higher than the baseline rate. For scenarios in which highway user costs increase, the effective VMT growth rate tends to be lower than the baseline rate. However, this effect is dampened for scenarios that assume that increases in the overall level of highway investment will be funded by increases in fixed or variable highway-user charges.

Demand elasticity is measured as the percentage change in travel relative to the percentage change in costs faced by users of the facility. Thus, an elasticity value of –0.65 would mean that a 10-percent increase in user costs would result in a 6.5 percent decrease in travel.

HERS Revenue and Pricing Analysis

The 2006 C&P Report introduced new HERS analytical procedures involving highway revenue and pricing analysis. Although these two procedures addressed related issues, they were initially implemented distinctly from one another within the model. For this report, these procedures have been revised to directly interact so that they can be used in conjunction with one another.

Congestion Pricing

The HERS congestion pricing procedures simulate the impact of imposing a charge on peak-period users of congested highway facilities. The congestion pricing feature was constructed using the existing HERS procedures for calculating delay and travel demand. HERS first calculates average user costs for an individual highway section in its usual fashion, and then derives the marginal congestion cost from the delay equations (coupled with value-of-time inputs). The difference between average costs and marginal costs represents the estimated congestion externality that each additional vehicle imposes on other users for that particular highway section. The model then applies a toll equal to this cost differential, requiring users to pay for this externality (thus improving efficiency), and determines a new equilibrium volume and price, reflecting the travel demand elasticity procedures described above.

The congestion pricing procedure is applied to peak period traffic on all roads with a volume/service flow (V/SF) ratio of 0.80 or greater. This is the threshold used in Chapters 4 and 7 to identify congested roads. While the primary congestion pricing strategy reflected in this report is described as "universal congestion pricing," this refers only to the implementation of these procedures on all congested roads. The size of the charge imposed varies considerably from section to section, as the impact of adding vehicles to heavily traveled and severely congested roadways is much greater than the impact of adding vehicles to moderately congested roadways.

HERS Revenue Analysis

The HERS revenue analysis procedures provide the option of imposing a "balanced budget" constraint on the results This was done by creating a mechanism to link the HERS levels of investment to the additional revenue that would be required to fund those investments.

The first step in the procedure is to determine the amount of revenue that must be raised to reach a target funding level. This calculation is based on the difference between the funding constraint specified for the run and base-year HERS-related expenditures, which were calculated from 2006 highway capital expenditure data. A multiplier is then applied to this difference to ensure that revenues would be sufficient to cover other capital expenditure types (including bridge rehabilitation and replacement and system enhancement) and functional systems (rural minor collector, rural local, and urban local) that are not modeled in HERS. The resulting total is then multiplied by a user-specified percentage indicating the portion of total revenue that should be assumed to come from system users in the form of a surcharge imposed on either a per-mile or a per-gallon basis.

For this report, the percentage of total revenue assumed to come from system users was set at 0 percent for both per-mile and per-gallon surcharges; for those analyses assuming funding from user-based sources, the per-mile surcharge percentage was set at 100 percent. This represents a departure from the 2006 C&P Report, which instead assumed a per-gallon surcharge.

The next step in the procedure is to compute a surcharge tax rate by dividing the amount of required revenue by the estimated total VMT and/or fuel consumption. Since the imposition of the surcharge would impact the price of driving and thus influence total VMT, the surcharge tax rate is computed iteratively until a new equilibrium of volume and price is established that generates approximately the amount of required revenue. The revenue and surcharge calculations are repeated sequentially for each funding period. However, during the benefit-cost analysis in each period (which typically extends over multiple periods), HERS assumes that the surcharge tax rates in that period are carried forward into future periods.

For this report, the revenue analysis procedure was modified so that the surcharge tax rate could be negative in cases where the level of investment being analyzed was below the current investment level, or if other revenues were available from congestion pricing as described in the next section. A negative surcharge represents the equivalent of reductions in existing user charges such as tolls or fuel taxes.

Linking of Congestion Pricing With Revenue Analysis Procedures

The analyses in this report that assume funding from variable rate user-based sources make use of both the congestion pricing and revenue analysis procedures described above. In determining the fixed rate VMT surcharge, HERS takes into account the total revenue that is required to be raised to achieve the target funding level as well as the revenue that would be generated from the variable congestion pricing charges. In cases where the congestion pricing revenue exceeds the amount of total revenue required, a negative fixed rate VMT charge is imposed, which has the effect of shifting some costs from off-peak highway users to peak-period highway users.

Because the fixed rate and variable rate charges both impact travel volumes through the travel demand elasticity procedures described above, the process of developing a new equilibrium volume and price is significantly more complex for analyses that incorporate both the congestion pricing and the revenue analysis procedures.

Operation Strategies and ITS Deployment

One of the key modifications to HERS featured in the previous report was the ability to consider the impact of highway operations strategies and ITS deployments on highway system performance. This feature is continued in this report with only minor modifications. Current and future investments in operations are modeled outside of HERS, but the impacts of these deployments were allowed to affect the internal calculations made by the model, and thus also affect the capital improvements considered and implemented in HERS. As discussed in Part IV, a longer-term goal would be to analyze operations as alternative investment strategies directly in HERS.

While numerous operations strategies are available to highway agencies, a limited number are now considered in HERS (based on the availability of suitable data and empirical impact relationships). The types of strategies analyzed can be grouped into four categories: arterial management, freeway management, incident management, and travel information as follows:

- Arterial Management
  - Signal Control
  - Electronic Roadway Monitoring (considered to be a supporting deployment necessary to other operations strategies)
  - Variable Message Signs (VMS)
- Freeway Management
  - Ramp Metering (preset and traffic actuated)
  - Electronic Roadway Monitoring (considered to be a supporting deployment necessary to other operations strategies)
  - VMS
  - Integrated Corridor Management (ICM)
  - Variable Speed Limits (VSL) (also known as “speed harmonization”)
- Incident Management (freeways only)
  - Incident Detection (free cell phone call number and detection algorithms)
  - Incident Verification (surveillance cameras)
  - Incident Response (on-call service patrols)

- Traveler Information
  - 511 systems
  - Advanced in-vehicle navigation systems with real-time traveler information (enabled by Vehicle-Infrastructure Integration deployment)
  - Incident response (on-call service patrols).

Creating the operations improvements input files for use in HERS involved four steps: determining current operations deployment, determining future operations deployments, determining the cost of future operations investments, and determining the impacts of operations deployments. Different levels and types of deployments can be selected for an individual scenario.

Current Operations Deployments

To determine current operations deployments on the HPMS sample segments, data were used from three sources: HPMS universe data, HPMS sample data, and data from the ITS Deployment Tracking System. The data assignments that were made reflected the fact that operations deployments occur over corridors (or even over entire urban areas, as with traffic management centers).

Future Operations Deployments

For future ITS and operations deployments, three scenarios were developed. For the "Continuation of Existing Deployment Trends" scenario, an examination of current congestion levels compared with existing deployments was made to set the congestion level by urban area size for each type of deployment. For the "Aggressive Deployment" scenario, an accelerated pace of deployment above existing trends was assumed, along with more advanced forms of operations strategies. The "Full Deployment" scenario is identical to the "Aggressive Deployment" scenario, except that it assumes that all deployments will occur immediately rather than being phased in over 20 years. The "Full Deployment" scenario is intended to illustrate the maximum potential impact of the strategies and technologies modeled in HERS on highway operational performance. *Exhibit A-1* identifies the strategies employed in the each scenario.

Operations Investment Costs

The unit costs for each deployment item were taken from the U.S. Department of Transportation's (DOT's) *ITS Benefits Database* and *Unit Costs Database* and supplemented with costs based on the ITS Deployment Analysis System (IDAS) model. Costs were broken down into initial capital costs and annual operating and maintenance costs. Also, costs were determined for building the basic infrastructure to support the equipment, as well as for the incremental costs per piece of equipment that is deployed. A major addition to operations deployment costs in this report is the inclusion of traffic signal replacement costs, which were not previously considered in the estimated capital costs.

Exhibit A-1

Types of Operations Strategies Included in Each Scenario

	Scenario	
Operations Strategy	**Continue Existing Trends**	**Aggressive and Full Deployment**
Arterial Management		
Signal Control	●	●
Emergency Management Vehicle Signal Preemption	●	●
VMS		●
Advanced Traveler Information		●
Freeway Management		
Ramp Metering	●	●
VMS	●	●
511 Traveler Information	●	
Advanced Traveler Information		●
ICM		●
VSL		●
Incident Management (Freeways Only)		
Detection	●	●
Verification	●	●
Response	●	●

Source: Highway Economic Requirements System.

Impacts of Operations Deployments

Exhibit A-2 shows the estimated impacts of the different operations strategies considered in HERS. These effects include the following:

- Incident Management: Incident duration and the number of crash fatalities are reduced. Incident duration is used as a predictor variable in estimating incident delay in the HERS model.
- Signal Control: The effects of the different levels of signal control are directly considered in the HERS delay equations.
- Ramp Meters, VMS, VSL, ICM, and Traveler Information: Delay adjustments are applied to the basic delay equations in HERS. VSL is assumed to have a small impact on fatalities as well.

Based on the current and future deployments and the impact relationships, an operations improvements input file was created for each of the two deployment scenarios. The file contains section identifiers, plus current and future values (for each of the four funding periods in the HERS analysis) for the following five fields:

- Incident Duration Factor
- Delay Reduction Factor
- Fatality Reduction Factor
- Signal Type Override
- Ramp Metering.

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 improvement cost updates reflected in the 2004 report were based on highway project data from six States (see Appendix A of that report for more information). Though adequate in most respects, that dataset was relatively thin in certain key areas. 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 (5,000 to 49,999), small urbanized (50,000 to 200,000), and large urbanized (more than 200,000). However, the data used to create values for the latter group did not include a significant number of projects in very large urbanized areas, and concerns were raised about the degree of construction cost comparability between medium-sized cities and much larger ones.

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 over 1 million in population. The HERS improvement cost matrix was adjusted further for this report, based on some additional analysis of the data previously collected.

Exhibit A-3 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 2006. However, the project level data on which these estimates are based reveal a considerable amount of variability in costs, which can be attributed to a number of location-specific factors. For example, while the unit costs per lane mile for adding an additional lane are based on project data that reflect the costs of improving bridges, modifying interchanges, and addressing environmental issues, these values represent the average costs for a typical project. However, a project with

Exhibit A-2

Impacts of Operations Strategies in HERS

Operations Strategy	Impact Category	Impact
Arterial Management		
Signal Control	Congestion/Delay	Signal Density Factor = n(nx+2)/(n+2) where n = # of signals per mile x = 1 for fixed time control 2/3 for traffic actuated control 1/3 for closed loop control 0 for real-time adaptive control/SCOOT/SCATS Signal Density Factor is used to compute zero-volume delay due to traffic signals
Electronic Roadway Monitoring	Congestion/Delay	Supporting deployment for corridor signal control (2 highest levels) and traveler information
EM Vehicle Signal Preemption		
VMS	Congestion/Delay	-0.5% incident delay
Freeway Management		
Ramp Metering		
Preset	Congestion/Delay	New delay = ((1 - 0.13)(original delay)) + 0.16 hrs per 1000 VMT
Traffic Actuated	Congestion/Delay	New delay = ((1 - 0.13)(original delay)) + 0.16 hrs per 1000 VMT
	Safety	-3% number of injuries and PDO accidents
Electronic Roadway Monitoring	Congestion/Delay	Supporting deployment for ramp metering and traveler information
VMS	Congestion/Delay	-0.5% incident delay
Integrated Corridor Management	Congestion/Delay	-10% total delay
Variable Speed Limits	Congestion/Delay Safety	-5% total delay -5% fatalities
Incident Management (Freeways Only)		
Detection Algorithm/ Free Cell	Incident Characteristics Safety	-4.5% incident duration -5% fatalities
Surveillance Cameras	Incident Characteristics Safety	-4.5% incident duration -5% fatalities
On-Call Service Patrols		
Typical	Incident Characteristics Safety	-25% incident duration -10% fatalities
Aggressive	Incident Characteristics Safety	-35% incident duration -10% fatalities
All Combined	Incident Characteristics Safety	Multiplicative reduction -10% fatalities
Traveler Information		
511 Only	Congestion/Delay	-3.0% total delay, rural only
Advanced Traveler Information	Congestion/Delay	-12% total delay, all highways

Source: Highway Economic Requirements System.

a large number of bridges, complicated interchanges, major environmental issues, and/or other extreme engineering issues would be expected to cost considerably more that a less complex project.

The values shown for adding a lane at "Normal Cost" reflect costs for projects where sufficient right-of-way is available or could be 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 not feasible and alternative approaches would be required in order to add capacity to a given corridor. Such alternatives would include the construction of parallel facilities, double-decking, tunneling, or the purchase of extremely expensive right-of-way. While HERS models these lane equivalents as though they are part of existing highways, some of this capacity could come in the form of new highways or investment in other modes of transportation facilities.

Exhibit A-3

Typical Costs Per Lane Mile Assumed in HERS, by Type of Improvements

(Thousands of 2006 Dollars Per Lane Mile)

Category	Reconstruct and Widen Lane	Reconstruct 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	$1,791	$1,170	$1,014	$415	$77	$2,301	$3,191	$3,191	$3,191
Rolling	$2,007	$1,200	$1,167	$442	$127	$2,495	$4,037	$4,037	$4,037
Mountainous	$3,806	$2,627	$1,933	$654	$267	$7,769	$9,095	$9,095	$9,095
Other Principal Arterial									
Flat	$1,398	$936	$845	$333	$52	$1,844	$2,639	$2,639	$2,639
Rolling	$1,579	$962	$961	$371	$86	$1,974	$3,186	$3,186	$3,186
Mountainous	$3,066	$2,166	$1,862	$524	$114	$6,969	$8,025	$8,025	$8,025
Minor Arterial									
Flat	$1,279	$823	$788	$295	$48	$1,676	$2,353	$2,353	$2,353
Rolling	$1,544	$911	$980	$318	$89	$1,921	$3,030	$3,030	$3,030
Mountainous	$2,565	$1,682	$1,862	$436	$201	$5,883	$7,060	$7,060	$7,060
Major Collector									
Flat	$1,347	$871	$814	$301	$62	$1,741	$2,351	$2,351	$2,351
Rolling	$1,474	$885	$915	$320	$83	$1,779	$2,894	$2,894	$2,894
Mountainous	$2,235	$1,385	$1,332	$436	$129	$3,766	$4,919	$4,919	$4,919
Urban									
Freeway/Expressway/Interstate									
Small Urban	$2,921	$2,023	$2,302	$491	$90	$3,665	$11,997	$4,939	$16,861
Small Urbanized	$3,140	$2,040	$2,381	$581	$119	$4,031	$13,157	$6,658	$22,728
Large Urbanized	$5,008	$3,340	$3,688	$779	$450	$6,702	$22,478	$9,765	$33,337
Major Urbanized	$10,017	$6,680	$7,157	$1,291	$900	$13,403	$55,892	$19,530	$74,714
Other Principal Arterial									
Small Urban	$2,546	$1,718	$2,107	$412	$91	$3,115	$10,175	$3,894	$13,290
Small Urbanized	$2,724	$1,739	$2,202	$487	$122	$3,375	$11,066	$4,804	$16,398
Large Urbanized	$3,891	$2,549	$3,222	$612	$392	$4,939	$16,502	$6,594	$22,510
Major Urbanized	$7,782	$5,098	$6,444	$988	$785	$9,878	$38,292	$13,189	$57,092
Minor Arterial/Collector									
Small Urban	$1,876	$1,298	$1,593	$301	$66	$2,301	$7,451	$2,809	$9,590
Small Urbanized	$1,965	$1,313	$1,608	$343	$81	$2,424	$7,876	$3,447	$11,767
Large Urbanized	$2,646	$1,755	$2,199	$420	$221	$3,360	$11,157	$4,486	$15,313
Major Urbanized	$5,292	$3,510	$3,327	$700	$441	$6,721	$38,292	$8,973	$47,385

Source: Highway Economic Requirements System.