Cost Analysis of Paved Shoulders

BENJAMIN H. COTTRELL, JR.

A cost analysis on paved shoulders was performed. The scope was limited to shoulders made of an asphalt plant mixture used to extend the mainline pavement. The literature review generally supported the notion that paved shoulders are economically justifiable under certain conditions. However, there was no consensus on the specific conditions. The survey results showed that 91.4 percent of the state departments of transportation (DOTs) surveyed use paved shoulders on two-lane roads to some degree. Most or all shoulders were paved by 42.9 percent of these DOTs, and 40.0 percent have threshold values to warrant paved shoulders. For the average new two- and four-lane road projects, the initial cost increases 16.7 and 8.3 percent, respectively, and there is a service life increase of 14.3 percent with 0.61-m (2-ft) paved shoulders. For a resurfacing project, initial cost increases of 72.0 and 36.0 percent are realized with a 0.61-m paved shoulder on two- and four-lane roads, respectively. Through an economic analysis using the equivalent uniform annual cost method, it was revealed that 0.61-m paved shoulders for new two-lane roads are economically justifiable under certain average daily traffic volumes that depend on the road's functional classification and terrain type. Paved shoulders of 0.61 m are not economically justifiable for most existing two-lane roads. For four-lane and six-lane roads, 0.61-m paved shoulders are economically justifiable for all new roads and for existing roads above certain average daily traffic volumes.

The literature on paved shoulders presents evidence that paved shoulders reduce maintenance costs and accidents and are economically justifiable under certain conditions. However, there is no consensus on the specific conditions under which paved shoulders should be used.

OBJECTIVE AND SCOPE

The objective of the study was to perform a cost analysis of paved shoulders. The scope of the analysis was limited to shoulders made of asphalt plant mixture used to extend the mainline pavement. Because there are only a small number of primary roads with portland cement concrete surfaces, concrete pavement and shoulders were omitted. By limiting the analysis to arterial and collector roads, the impact of paved shoulders on arterial and collector roads may be evaluated and reviewed before considering implementation on local roads. Moreover, the potential savings in the cost of maintenance and the possible reduction in accidents are higher for arterial and collector roads. Although the use of paved shoulders for bicyclists is receiving much attention, the focus of this effort was on cost savings related to maintenance and accidents. Other research efforts are under way to address methods to accommodate bicyclists.

Virginia Transportation Research Council, Box 3817 University Station, Charlottesville, Va. 22903.

METHODOLOGY

Three tasks were undertaken to achieve the study's objective:

1. Literature on paved shoulders was reviewed.
2. A survey of other state departments of transportation (DOTs) on the use of paved shoulders was conducted.
3. A cost analysis on paved shoulders was performed, the methodology of which is described in following sections.

Literature Review

Although many studies of paved shoulders have been performed, many are either outdated (i.e., more than 20 years old) or flawed because of questions about the reliability of the data (study design and quality of the data) or the analysis of the data and results (statistical tests and interpretation of findings). Seven pertinent reports were reviewed (*1*).

There are numerous similarities and differences in the methods of analysis in and in the findings of these studies. The notion that paved shoulders are economically justifiable under certain conditions was generally supported. However, there is no consensus on what these conditions are.

Survey of State DOTs on Paved Shoulders on Two-Lane Roads

State DOTs were surveyed to determine their policies on paved shoulders on two-lane roads. Thirty-five state DOTs responded to the survey for a 70 percent response rate.

Paved Shoulder Use

Thirty-two of the thirty-five state DOTs (91.4 percent) used paved shoulders on two-lane roads in their design standards to some degree. Minimum paved shoulder widths of at least 0.61 m (2 ft) were used by 21 of the 32 state DOTs (65.6 percent). A 0.61-m minimum paved shoulder is used by 10 of the 32 state DOTs (31.3 percent). Most or all shoulders were paved by 15 state DOTs (42.9 percent). Paved shoulder criteria and the corresponding number of state DOTs are given in Table 1.

From a review of demographics and paved shoulder use, it was revealed that all of the northwestern state DOTs pave all shoulders. The winters are long and snowplows are used frequently, and paved shoulders provide a smoother, safer place for plows to operate. The ability of paved shoulders to keep water out of the base and subgrade is even more im-

TABLE 1 Paved Shoulder Criteria of State DOTs

Paved Shoulder Criteria	Number of State DOTs (percent)
Most or all shoulders paved	15 (42.8)
ADT and functional classification	4 (11.4)
ADT only	3 (8.6)
All principal arterials only	3 (8.6)
ADT and truck volume	3 (8.6)
Generally no paved shoulders	3 (8.5)
Criteria for RRR and construction/reconstruction only	2 (5.7)
ADT for new and reconstruction	1 (2.9)
Truck volume	1 (2.9)
Totals	35 (100.0)

portant when snow is plowed onto the shoulders. No other demographic trend was noted.

Paved Shoulder Benefits

State DOTs were asked to identify the benefits of paved shoulders. Of the 35 state DOTs, 21 (60 percent) responded to this question. The responses are shown in Table 2. Ten state DOTs (28.6 percent) identified lateral support to the highway (longer service life) and reduced maintenance costs as benefits. In addition, other benefits mentioned that are of interest to this study are improved drainage, provision of a recovery area, edge raveling and pavement drop-off control, and decreased accident rates.

Cost Analysis

Cost analysis examines costs under the current Virginia DOT (VDOT) design policy of using unpaved shoulders and the proposed use of 0.61-m asphalt paved shoulders. The analysis focuses on two-lane minor arterials and collector roads and four-lane principal and minor arterials on the basis of functional classification. VDOT data are collected by administrative classification. Consequently, data for the primary system were used because the major target groups are in the primary system.

TABLE 2 Benefits of Paved Shoulders

Benefits	No. of State DOTS
Lateral Support to the Highway (Longer SVC Life)	10
Reduced Maintenance Costs	10
Accommodating Stopped Vehicles/Emergency Parking	6
Improved Drainage of Roadway	6
Providing a Recovery/Maneuvering	6
Edge Raveling/Pavement Drop-off Control	5
Decreased Accident Rate, Protecting Errant Vehicles	5
Bicycle Safety	4
Reduced Damage by Encroachment of Vehicles	3
Providing a Traffic Lane During Highway Rehab Work	2
Increased Safety for Pedestrians	2
Smoother, Safer Snow Plow Operation	2
A Cleaner Highway/Aesthetic Value	2
Providing for Agricultural Equipment	1
Providing a Sense of a Safe, Open Highway	1
Increased Sight Distance at Horizontal Curves	1
Maintain Capacity	1
Compensation of Off-Tracking	1
Providing a Bus Stop Area	1

Initial Cost

Initial costs were considered for constructing a new road and for resurfacing an existing road. The initial pavement cost for an average project [7.32-m (24-ft) width] and an average project with full-depth 0.61-m paved shoulders is given in Table 3 for a new road with a typical VDOT asphalt concrete mixture at 152.4-mm (6-in.) depth and a typical surface treatment at 38.1 mm (1.5 in.) over a 152.4-mm cement-treated aggregate base. The cost for resurfacing an existing 7.32-m-wide road and resurfacing with 0.61-m paved shoulders through trench widening provide for 38.1 mm of a typical surface treatment and traffic control. The trench widening consists of cutting out sod to make a 0.61-m trench on each side, filling the trench with 152.4-mm aggregate stone (152.4 mm of a typical VDOT-type asphalt concrete mixture), and overlaying with 38.1 mm of a typical surface treatment to make the shoulder even with the existing pavement. Service life information is also provided in Table 3. The initial cost increase on the average new road project is $21,163, or 16.7 percent. The initial cost increase for the average resurfacing project is $22,356, or 72.0 percent. Trench widening accounts for the increase. The corresponding increase in service life is 14.3 percent for both types of roads. The 7-year service life is based on historical data that reveal a 7.3-year average service life for primary roads. The expected 8-year service life with paved shoulders was based on the experiences of the North Carolina DOT and engineering judgment.

Maintenance Costs

Two types of maintenance activities are related to the use of paved shoulders: general shoulder maintenance (primarily for aggregate shoulders) and edge-of-pavement patching. Computerized printouts of maintenance expenditures for FY 1987–1988 for shoulder maintenance and patching on the primary system were provided by the maintenance division.

The total number of centerline kilometers of primary roads was used to determine the cost per kilometer. On the primary system, 69.5 percent of the kilometers are two-lane roads.

TABLE 3 Cost and Service Life Information

	New Road	Resurfacing Existing Road
Average project cost/kilometer	$214,292	$50,000
Cost/kilometer with 0.61-m shoulders	$249,974	$86,000
Cost/kilometer increase	$ 35,682	$36,000
Percent increase	16.7	72.0

Average project service life = 7 yrs
Service life with 0.61-m shoulders = 8 yrs
Service life increase = 1 yr
Percent increase = 14.3

The actual maintenance expenditures on two-lane primary roads are not available from the computerized records.

The North Carolina DOT staff conservatively estimates that a 75 percent reduction in shoulder maintenance is realized when the pavement is extended into the shoulder 0.61 m. From the state DOT survey, Iowa DOT listed the following annual costs per kilometer: for unpaved shoulders [earth/granular 1.8 to 3.1 m (6 to 10 ft) wide], shoulder maintenance cost was $350; for paved shoulders, shoulder maintenance cost was $130. Maintenance cost saving per kilometer resulting from paved shoulders was $220, or 62.9 percent. Consequently, shoulder maintenance cost saving of 62.9 percent for paved shoulders was used in the analysis. An estimated 25 percent reduction in the cost of pavement patching could be realized as a result of less raveling, less cracking, and improved drainage. The potential cost savings for asphalt shoulders on two-lane primary roads are calculated below using these estimated reductions.

VDOT average annual shoulder maintenance
cost per kilometer = $369
Expected savings with paved shoulder per kilometer = $232
Annual shoulder maintenance cost with
paved shoulder per kilometer = $137

VDOT average annual pavement patching
cost per kilometer = $343
Expected savings with paved shoulders per kilometer = $86
Annual pavement patching costs with paved
shoulders per kilometer = $257

VDOT total average annual shoulder-related
maintenance cost per kilometer = $712
Expected savings with paved shoulders per kilometer = $318
Annual shoulder-related maintenance cost
per kilometer with paved shoulders = $394

Accident Analysis

There were two objectives in the accident analysis: (a) to determine the expected reduction in accidents attributable to the use of 0.61-m paved shoulders, and (b) to determine the expected cost savings from the reduction in accidents.

Accident Reduction The accident prediction model developed by Zegeer et al. was selected because it was developed in a recent study based on an extensive sample size of 3,075 km (4,951 mi) of two-lane roads in seven states (*2,3*). This model was selected because (a) it includes head-on and sideswipe accidents, as well as single-vehicle accidents (all of which logically should be affected by roadway geometric features); (b) the coefficients and the R^2-value, 0.456, appear to be reasonable and consistent with the literature; and (c) terrain effects (flat, rolling, or mountainous) are incorporated into the model (*2*). The accident prediction model/equation is (*2*)

$$\mathrm{AO/KM}/Y = 0.0019(\mathrm{ADT})^{0.8824}(0.8786)^{3.28W} \times (0.9192)^{3.28\mathrm{PA}}(0.9316)^{3.28\mathrm{UP}} \times (1.2365)^{H}(0.8822)^{\mathrm{TER1}}(1.3221)^{\mathrm{TER2}} \div 1.61 \quad (1)$$

where

AO/KM/Y = related accidents (i.e., single-vehicle plus head-on plus opposite-direction sideswipe plus same-direction sideswipe accidents) (per km/year);
ADT = average daily traffic;
W = lane width (m);
PA = average paved shoulder width (m);
UP = average unpaved (i.e., gravel, stabilized, earth, or grass) shoulder width (m);
H = median roadside hazard rating (scale of 1 to 7 with 7 as the highest hazard rating);
TER1 = 1 if flat, 0 otherwise;
TER2 = 1 if mountainous, 0 otherwise.

The conditions for use are as follows:

1. Two-lane rural roads with an ADT of 100 to 10,000.
2. Lane widths of 2.4 to 3.6 m (8 to 12 ft).
3. Shoulders 0 to 3.6 m (12 ft) wide, that are paved or unpaved (or partly paved and partly unpaved).

Because the current concern is not site-specific, a median roadside hazard rating in the middle (4 to 6) was assumed, and 5 was selected as recommended in the informational guide (*3*). Although a confidence interval for AO/KM/Y was desired, it was not determined because the standard error of the estimate was unknown.

A four-step process was used to determine the accident reduction and cost savings on the basis of the reduction in accident frequency for 0.61-m paved shoulders compared with the existing unpaved shoulder standards.

1. VDOT's road and bridge standards (*4*) were used to select ADT ranges (with some expansion), two functional road classes (arterials and collectors), and three terrain types, which in turn determine the lane and shoulder widths.
2. For improved accuracy, the equation was entered on a microcomputer spreadsheet program in lieu of using nomographs provided in the information guide. The equation was entered twice: (a) for the current unpaved shoulder design width, and (b) for the proposed 0.61-m paved shoulder plus the remaining shoulder design width unpaved. All other variables are the same for a given road design.
3. The reduction in the number of related accidents per kilometer per year was determined for the 0.61-m paved shoulder versus the standard shoulder design. This difference and the corresponding cost savings were calculated automatically with entry of the variables in the model.
4. Two matrix tables were developed: one for each road class for the accident frequency reduction and one for the related cost savings for various ADT and terrain types.

When the current road design unpaved shoulder width is changed to a 0.61-m paved shoulder and the remaining width is left unpaved, a 2.6 percent reduction in accident frequency is realized.

Accident Cost Savings FHWA's recommended approach for determining motor vehicle accident costs was used (*5*). FHWA's recommended accident costs are $1.5 million/fatality, $11,000/injury, and $2,000/vehicle for property damage–only (PDO) accidents. These costs per incident were used instead of cost per accident to include accident experience in Virginia for the specific accident types and accident severity. The following equation was used:

$$\begin{aligned}\text{average cost per accident} &= (\text{percentage of fatal accidents} \\ &\times \text{number of fatalities/fatal accident} \\ &\times \text{cost/fatality} + \text{percent of injury accident} \\ &\times \text{number of injuries/injury accident} \\ &\times \text{cost/injury} + \text{percent of PDO accidents} \\ &\times \text{number of vehicles/PDO accident} \\ &\times \text{cost/vehicle}) \div 100 \qquad (2)\end{aligned}$$

Average cost per accident was determined for head-on, sideswipe same-direction and opposite-direction, and fixed-object, off-the-road accidents on the primary system. Using Virginia accident data from 1985 to 1987 (*6–8*), the equation yields

$$\begin{aligned}\text{average cost per accident} &= (1.9401 \times 1.1812 \\ &\times 1{,}500{,}000 + 42.1759 \\ &\times 1.4613 \times \$11{,}000 \\ &\times 55.8840 \times 1.4703 \\ &\times \$2{,}000) \div 100 \\ &= \$42{,}797\end{aligned}$$

FHWA's approach also states that the accident costs should be updated at least every 2 years. Consequently, a 7.8 percent increase was used on the basis of the increase in the consumer price index (CPI) from 1986 (the base year) to 1988 (*9*). Consequently, the average cost per accident becomes $46,135.

The cost saving per kilometer per year was determined by multiplying the average cost per accident and the accident frequency per kilometer per year. The accident cost savings range from $54 to $2,954, depending on type of highway, ADT, and terrain.

For principal arterials and four- and six-lane divided minor arterials, the average cost per accident was determined for sideswipe same direction, and fixed-object, off-the-road accidents on the primary system. Including increases from the CPI, the average cost per accident for divided roads was $33,186.

Analysis

The two alternatives were analyzed using the equivalent uniform annual cost (EUAC) method (*10*) as follows:

$$\text{EUAC}_A = -I(\text{CR} - i \text{ percent} - \text{SL}) - \text{SM} - \text{PC} \qquad (3)$$

where

EUAC_A = equivalent uniform annual cost for Alternative *A*,
I = initial cost,
CR = capital recovery factor,
i percent = interest rate,
SL = service life (years),
SM = annual shoulder maintenance cost, and
PC = annual pavement patching cost.

An interest rate of 5.0 percent is used because the real-time value of money is 4.5 to 5.0 percent.

When comparing the EUAC of the current design (no paved shoulder) with the 0.61-m paved shoulder design, the latter has an EUAC $701 higher than the current design before accident cost savings are considered. In other words, an annual accident savings of $701 or more is necessary to economically justify the use of paved shoulders. The next step is to determine the ADT threshold that will result in the accident cost savings being equal to $701 for the three terrain types for each functional classification. At this ADT value, the costs of the two alternatives are equal; any ADT greater than the threshold will yield a savings for the 0.61-m asphalt paved shoulder alternative.

RESULTS

Two-Lane Roads

The results of the analysis (including ADT threshold values) are shown in Table 4 for new roads and for resurfacing existing roads. The ADT threshold values for new roads can be expected to be exceeded by some minor arterials and collectors.

The ADT threshold values for resurfacing existing roads are so high that almost all two-lane roads will not exceed the threshold values; therefore, the use of 0.61-m paved shoulders

TABLE 4 Analysis Results for Two-Lane Roads with a 0.61-m (2-ft) Paved Shoulder

	New Road	Resurfacing Existing Road
Difference in EUAC (current-proposed)	701	2,579
Minor Arterial		
ADT Threshold by Terrain Type		
Mountainous	3,705	16,210
Rolling	5,085	22,240
Level	5,860	25,635
Collector Roads		
ADT Threshold by Terrain Type		
Mountainous	2,690	11,755
Rolling	3,690	16,130
Level	4,250	18,595

by trench widening with the resurfacing of existing two-lane roads is not economically justified.

Four-Lane Roads

The analysis results for one direction of a four-lane road are presented in Table 5. For a new road, a savings of $1,031 is realized with a 0.61-m paved shoulder. The increase in service life more than offsets the initial cost increase and accounts for $695 or 67 percent of the savings. The remaining savings ($318) is from maintenance cost reductions. These savings are realized without considering accident reductions. Paved shoulders that are 0.61 m wide are economically justified for all new four-lane roads.

The ADT thresholds for four-lane existing roads should be used with caution. The accident model used was developed for two-lane roads. The model was used to determine the reduction in accidents expected when a paved shoulder exists. It is assumed that this accident reduction for four-lane roads would be similar to the accident reduction for two-lane roads. The same primary system accident data were used for both two- and four-lane roads. Moreover, there was no model available to predict such accident reductions specifically for four-lane roads.

Many four-lane undivided and divided roads exceed the threshold values. Therefore, the use of 0.61-m paved shoulders is economically justified with the resurfacing of existing roads with certain ADT volumes.

Limitations for Use of ADT Thresholds for Paved Shoulders

A 0.61-m paved shoulder provides a benefit by removing the pavement edge away from the travel lane. Consequently, reductions in shoulder maintenance and pavement edge raveling repairs are realized. To ensure that the 0.61-m paved shoulder is not used as part of a wider travel lane, it is required that all roads eligible for paved shoulders have a road width of 6.1 m or greater and have edgeline and centerline pavement markings. To be effective, edgeline markings must be installed to maintain a 0.61-m paved shoulder. In other words, the lane width must remain the same after installation of the paved shoulders.

Summary

This analysis of the alternatives was conducted with the available data. The analysis has a reasonable level of confidence. Although they are not exact, maintenance-related costs and accident costs are supported by the information available.

DISCUSSION OF RESULTS

Paved Shoulders for All Roads Versus Selected Roads

A policy to pave 0.61 m of shoulders on all roads with pavement widths of 6.1 m or wider would provide the most wide-

TABLE 5 Analysis Results for One Direction of a Four-Lane Road with 0.61-m (2-ft) Right Shoulder

	New Road	Resurfacing Existing Road
Difference in EUAC	−1,013	850
Undivided Road		
One Direction ADT Threshold by Terrain Type		
Mountainous	0	4,605
Rolling	0	6,320
Level	0	7,285
Divided Road		
ADT Threshold by Terrain Type		
Mountainous	0	5,700
Rolling	0	9,180
Level	0	10,580

spread impact. The design and programming process would be facilitated compared with a process with a decision-making step to determine whether paved shoulders are required. Blanket use of paved shoulders would yield statewide uniformity and consistency. Fifteen state DOTs (42.9 percent) pave most or all shoulders on arterials/primary/state roads.

By limiting paved shoulders to selected roads, usage may be restricted to roads that yield lower EUAC. Fourteen state DOTs (40 percent) use a threshold to determine when to use paved shoulders. The analysis indicated that paved shoulders provide a savings compared with the current design for new and existing roads with an ADT equal to or above those identified in the previous section. However, 0.61-m paved shoulders are not economically justified for existing two-lane roads. Paved shoulders are economically justified for all new four-lane roads, selected new two-lane roads, and existing four-lane roads.

Opposition from Subdivision Developers

If subdivision streets are required to have 0.61-m paved shoulders, then VDOT can expect to receive a considerable number of protests from developers. The additional costs will likely be passed on to home buyers. The costs can be justified based on lower maintenance costs for VDOT and safer roads for the subdivision residents. Paved shoulders should be used on new subdivision collector streets that exceed the ADT threshold values.

Paved 2-ft Shoulders Versus 1-ft Wider Lane and 1-ft Paved Shoulder

When a current unpaved shoulder is changed to a 0.61-m paved shoulder with the remainder unpaved, a 2.6 percent reduction in accident frequency is realized. When the lane width is increased by 0.31 m (1 ft) and 0.31 m of the shoulder width is paved, a 6.9 percent reduction in accident frequency is realized. An additional 4.3 percent reduction in accident frequency is realized for a 0.31-m wider lane and 0.31-m paved shoulder compared with the 0.61-m paved shoulder. When the design lane width is less than 3.6 m, substantial additional accident cost savings may be experienced without an increase in the initial cost. For example, a $701 accident cost savings increases to $1,844. The lane widening and paved shoulder combination is promising. Another alternative is to widen the lanes to 3.6 m and provide 0.61-m paved shoulders. On the other hand, based on the road design standards (*4*) and ADT threshold values, a 3.6-m lane width [3.36 m (11 ft) for selected mountainous areas] is expected at most locations that justify a 0.61-m paved shoulder.

One Direction of a Six-Lane Road

Because the conditions under which 0.61-m paved shoulders are economically justifiable on two- and four-lane roads have been identified, it is suspected that there may be some interest in identifying such conditions for six-lane roads. This analysis is presented in Table 6. As with four-lane roads, the accident analysis must be used with caution.

A 0.61-m paved shoulder is economically justified for all new six-lane roads. VDOT does not typically design new six-lane undivided roads. However, six-lane undivided roads sometimes result from the widening of a four-lane undivided road. The resurfacing of existing roads with 0.61-m paved shoulders is economically justifiable for many six-lane roads.

Paved 4-ft Shoulders for Bicyclists

It was suggested that a minimum paved shoulder of 1.22 m be used to accommodate bicyclists. This recommendation was based in part on VDOT's interest and support for accommodating bicyclists. The VDOT Bicycle Advisory Committee was established to examine the extent to which VDOT policies and standards accommodate bicyclists. The preferred method for accommodating bicyclists, be it a paved shoulder, a wider right lane, or other alternative, has not been identified. Nevertheless, the results of the analysis for 1.22-m (4-ft) paved shoulders are shown in Table 7 for two-, four-, and six-lane roads, respectively.

TABLE 6 Analysis Results for One Direction of a Six-Lane Road with 0.61-m (2-ft) Right Shoulder

	New Road	Resurfacing Existing Road
Difference in EUAC	− 2,217	568
Undivided*		
ADT Threshold by Terrain Type		
Mountainous	0	2,920
Rolling	0	4,005
Level	0	4,620
Divided		
ADT Threshold by Terrain Type		
Mountainous	0	4,240
Rolling	0	5,820
Level	0	6,710

*VDOT typically does not design new six-lane undivided roads.

TABLE 7 ADT Threshold Values for 1.22-m (4-ft) Paved Shoulders

	Mountainous	Rolling	Level
New Two-Lane Minor Arterials	12,800	17,565	20,245
Existing Two-Lane Minor Arterials	19,670	29,995	31,115
New Collector	9,285	12,740	14,685
Existing Collector	14,270	19,580	22,565
New Four-Lane Undivided Road	1,460	2,355	2,715
Existing Four-Lane Undivided Road	7.505	10,295	11,865
New Four-Lane Divided Road	2,125	3,420	3,940
Existing Four-Lane Divided Road	9,280	14,955	17,235
All New Six-Lane Undivided, and Divided Roads	0	0	0
Existing Six-Lane Undivided	6,580	9,030	10,410
Existing Six-Lane Divided	9,560	13,120	15,120

Notes: 1. Principal arterials are four- and six-lane divided roads. Multilane minor arterials are either divided or undivided.

2. For two-lane roads, the ADT threshold values are for total ADT and for a 0.61-m paved shoulder on both sides of the roadway. For multilane highways, the ADT threshold values are for one direction only and for a 0.61-m paved right shoulder.

3. VDOT typically does not design six-lane undivided roads.

Only on a limited number of new two-lane roads and practically on no existing two-lane roads can 1.22-m paved shoulders be economically justified (see Table 7). On the majority of new four-lane roads and a limited number of existing four-lane roads, 1.22-m paved shoulders can be economically justified. On all new six-lane roads and a limited number of existing six-lane roads, a 1.22-m paved shoulder can be justified. Paved shoulders are economically justified for a greater number of road kilometers than 1.22-m paved shoulders. Consequently, the potential cost savings are greater with implementation of the 0.61-m paved shoulder.

CONCLUSIONS

1. From a survey of state DOTs, it was found that

–Paved shoulders were used to some degree by 32 of 35 state DOTs (91.4 percent);

–Most or all shoulders are paved by 15 state DOTs (42.9 percent);

–Fourteen state DOTs (40.0 percent) have threshold values to warrant paved shoulders;

–Minimum paved shoulder widths greater than or equal to 0.61 m were used by 21 of 32 state DOTs (65.6 percent);

–Paved shoulders of 0.61 m are used by 10 of the 32 state DOTs (31.3 percent); and

–Ten state DOTs (28.6 percent) each noted lateral support of the highway and reduced maintenance costs as benefits of paved shoulders;

2. From the cost analysis, it was found that

–Initial cost increases on the average new road project are 16.7 and 8.3 percent with a corresponding service life increase of 14.3 percent when 0.61-m asphalt paved shoulders are used on two- and four-lane roads, respectively;

–When the current road design unpaved shoulder width is changed to a 0.61-m paved shoulder and the remaining width is unpaved, a 2.6 percent reduction in accident frequency is realized;

–An annual total maintenance cost savings of $512 is expected when using 0.61-m paved shoulders; therefore, an annual accident cost savings per kilometer of $1,129 is needed to economically justify 0.61-m paved shoulders on new roads;

–Paved shoulders 2 ft wide are economically justifiable on (a) all new four-lane roads and (b) new two-lane roads and existing four-lane roads that exceed ADT threshold values. They are not economically justifiable on most existing two-lane roads; and

–Roads that are eligible for paved shoulders must be greater than 6.1 m wide and have edgeline and centerline markings. For the paved shoulders to be effective, edgeline markings must be installed to maintain a 0.61-m paved shoulder.

3. Discussions on other issues concluded that

–Paved shoulders of 0.61 m are economically justified on all new six-lane roads and many existing six-lane roads;

–Paved shoulders of 1.22 m are economically justified on (a) all new six-lane roads, (b) a majority of new four-lane roads, and (c) a limited number of new two-lane roads and existing four- and six-lane roads; and

–The potential for installation and subsequent cost savings for 0.61-m paved shoulders is much greater than that for 1.22-m paved shoulders.

RECOMMENDATIONS

On the basis of the results of this study, the following recommendations are made: VDOT should consider using 0.61-m asphalt paved shoulders (mainline pavement extended) for all new four- and six-lane roads and for all roads that have ADT values that exceed those shown in Table 8. For existing roads that exceed the threshold, 0.61-m paved shoulders should be installed when resurfacing is scheduled. For paved shoulders to be considered, the roadway width must be 6.1 m or wider, and the road must have edgeline and centerline pave-

TABLE 8 Recommended ADT Threshold Values for 0.61-m (2-ft) Paved Shoulders

	Mountainous	Rolling	Level
New Two-Lane Minor Arterials	3,705	5,085	5,860
New Collector	2,690	3,690	4,250
All New Four- and Six-Lane undivided, and divided roads	0	0	0
Existing Four-Lane Undivided Road	4,605	6,320	7,285
Existing Four-Lane Divided Road	5,700	9,180	10,580
Existing Six-Lane Undivided	2,920	4,005	4,620
Existing Six-Lane Divided	4,240	5,820	6,710

Notes: 1. Principal arterials are four- and six-lane divided roads. Multilane minor arterials are either divided or undivided.

2. For two-lane roads, the ADT threshold values are for total ADT and for a 0.61-m paved shoulder on both sides of the roadway. For multilane highways, the ADT threshold values are for one direction only and for a 0.61-m paved right shoulder.

ment markings. After installation of the 0.61-m paved shoulders, centerline markings must be installed to keep the lane width unchanged and to maintain a 0.61-m paved shoulder. It may be desirable to round up the threshold values or otherwise simplify these values. For existing roads that have lane widths less than 3.6 m, it is suggested that the need to widen the lanes be determined through the appropriate VDOT process.

ACKNOWLEDGMENT

The study was supported by HPR funds administered through FHWA.

REFERENCES

1. B. H. Cottrell, Jr. *Review of Paved Shoulders*. Virginia Transportation Research Council, Charlottesville, Va., 1990.
2. *Safety Effects of Cross-Section Design on Two-Lane Roads*, Vol. 1. Final Report FHWA-RD-87/008. FHWA, U.S. Department of Transportation, 1987.
3. *Safety Cost-Effectiveness of Incremental Changes in Cross-Section—Informational Guide*. Report FHWA/RD-87/094. FHWA, U.S. Department of Transportation, 1987.
4. *Road and Bridge Design Standards*. Virginia Department of Transportation, Richmond, Va., 1989.
5. *Motor Vehicle Accident Costs*. FHWA Technical Advisory T7570.1. FHWA, U.S. Department of Transportation, 1988.
6. *1985 Summary of Accident Data*. Virginia Department of Transportation, Richmond, Va., 1985.
7. *1986 Summary of Accident Data*. Virginia Department of Transportation, Richmond, Va., 1986.
8. *1987 Summary of Accident Data*. Virginia Department of Transportation, Richmond, Va., 1987.
9. *1989 Annual Highway Safety Improvement Report*. Virginia Department of Transportation, Richmond, Va., 1989.
10. R. Winfrey. *Economic Analysis for Highways*. International Textbook Company, Scranton, Pa., 1969.

Publication of this paper sponsored by Committee on Transportation Economics.