In addition, feeder trucks would be useful where the source of the material is not close. We estimate three feeder trucks per distributor. At $25.00 per hour each, the total equipment cost is $104.90 per hour.

For personnel, five driver-operators are appropriate. The extra driver would be available for relief or for equipment operation on the distributor. The billing cost for heavy-truck drivers, according to Means, is $19.75 per hour. Therefore, the total labor cost is $98.75 per hour.

Following the information from the Washington State Department of Transportation, we assume an average vehicle speed of three miles per hour. The assumed application width is ten feet. The coverage rate is, then

$$3 \text{ mi/hr} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.0929 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ adj} = 12{,}890 \text{ m}^2/\text{hr}$$

Road oil costs $0.31 per sq meter. Multiplying this by the hourly coverage gives an hourly material cost of $3995.90. Total cost comes to $4199.55 per hour. Dividing each of the hourly cost categories by the hourly coverage gives the cost per sq meter as shown in Table A.1.5.10.2. Because of their consistency with each other, these figures are taken as the representative costs for application of road oil. Table A.1.5.10.3 summarizes the information on the application of road oil.

TABLE A.1.5.10.2. Costs Per Square Meter for Road Oil Distribution

	Total	Labor	Equipment	Material
$/hr	4199.55	98.75	104.90	3995.90
$/m^2	0.3258	0.0077	0.0081	0.31

TABLE A.1.5.10.3. Summary of Road Oil Application Data for Asphalt Roads

Source	Rate (m^2/hr)	Cost (1982 $/m^2) Total	Labor	Equipment	Material
Wash. Dept. of Trans.	15,468	0.52	--	--	0.31
Means	12,890	0.326	0.008	0.008	0.310
Representative	12,890	0.326	0.008	0.008	0.310

A.1.5.11 Thin Asphalt Overlay

Three sources provided information on the cost of placing a thin layer of pavement--one to two inches thick. Such a pavement layer is most likely to be applied after the road surface has been planed. When a new surface of asphalt is put on an asphalt base, the new asphalt is preceded by application of a tack coat. Beyond its intended function to bind the two layers of asphalt, the tack

coat also will fix any existing radiation on the road surface. While the cost of applying a tack coat was listed separately above, the following applications of asphalt on asphalt include the cost of a tack coat in the total.

The Policy Planning unit of the U.S. Federal Highway Administration provided selected data from a Federal Highway Administration publication entitled The Status of the Nation's Highways: Conditions and Performance, published in January, 1981. In Tables 4-4 through 4-8 the cost of resurfacing roads cross-tabulated by various factors is presented. For example, the cost per mile of resurfacing a one- to three-lane minor collector in a rural area on flat terrain was given as $69,000. In contrast, the cost of resurfacing a four lane undivided highway in a built-up area is listed as $389,000 per mile. Using the Federal Highway Administration's estimate of 11 feet for lane width, the cost per sq meter of resurfacing varies from $1.42 to $23.60. The former figure is for a minor collector on flat terrain in a rural area and includes six to eight feet of shoulder on each side of the road. The higher figure is for a pavement overlay on two lanes plus shoulders of an urban undivided highway in a built-up area. Neither the tables nor personal conversation made it quite clear why the cost of resurfacing a road was so highly variable and so sensitive to the type of area. Also, no data are available describing the inputs or the relative magnitudes of their costs. After adjusting for radiation control measures, these figures range from $1.62 to $26.97 per sq meter.

The State of Washington Department of Transportation reports that the cost of putting a one- to 1.5-inch layer of asphalt on existing pavement is about $1.50 per sq yard, or about $1.79 per sq meter. In addition to this amount, the source advises that an extra ten percent should be included for "mobilization." This involves getting the equipment to the site and so forth. The cost, including the extra ten percent and one hour adjustment, is $2.25 per sq meter.

This paving operation requires a mobile asphalt plant, a front-end loader, two tanker trucks to supply asphalt, a paving machine, three rollers, and ten trucks. The personnel required would be three operators for the asphalt plant and the loader, two teamsters for the asphalt supply trucks, five operators for the paving machine and the three rollers, ten drivers for the trucks, and two laborers.

According to this source, paving is about three times faster than planing, meaning that the speed for paving is nine lane miles per day. Adjusting for one hour per shift lost to radiation control activities, the average hourly production is:

$$9 \text{ mi} \times 5280 \text{ ft/mi} \times 10 \text{ ft wide} \times 0.093 \text{ m}^2/\text{ft}^2 \times 7/8 \text{ adj} \div 8 \text{ hr} = 4834 \text{ m}^2/\text{hr}$$

The Los Angeles Department of Public Works reported that resurfacing costs $25.80 per ton of asphalt placed. This source added that a ton of asphalt will

cover 160 sq feet, one inch deep. This is a surface area of 14.88 sq meters. Thus, the cost per sq meter, with the one-hour adjustment, is

$$\frac{\$25.80/\text{ton}}{14.88\ \text{m}^2/\text{ton}} \times 8/7 \text{ adj} = \$1.98/\text{m}^2$$

This source explained that their paving machine is capable of applying 600 tons of asphalt per hour. This represents about 1.8 lane miles per hour or, equivalently, 8928 sq meters per hour. However, they cannot achieve this rate, since their asphalt plant only produces 1500 tons of asphalt per day. Even so, their actual paving rates do not fully utilize the asphalt plant's capacity. In a very good day, 1000 tons are applied. In a normal day, approximately 800 tons are applied. Adjusting for loss of a shift hour for special radiation control activities, 700 tons per day represent a better expectation for paving in a contaminated environment. This will cover slightly over two lane miles. The average coverage rate is 1302 sq meters per hour.

Information taken from Means Site Work Cost Data 1982 (p. 75) and from Engelsman's 1981 Heavy Construction Cost File (p. 140) are in close agreement, but differ significantly from cost data supplied by the Washington State Department of Transportation and the Los Angeles Department of Public Works. As can be seen in Table A.1.5.11.1, rates from Means and Engelsman are very close to each other but very much below the other two. Also, the costs reported in the two volumes are somewhat higher than the costs reported by the two governmental agencies. We can offer no explanation for the discrepancy.

TABLE A.1.5.11.1. Summary of Cost and Productivity Data for Paving Asphalt Roads with a One-Inch Layer of Asphalt

Source	Rate (m^2/hr)	Cost (1982 \$/m^2) Total	Labor	Equipment	Materials
Fed. Hwy. Admin.	--	1.62 26.97	--	--	--
Wash. Dept. of Trans.	4834	2.25	--	--	--
L.A. Pub. Works	1302	1.98	--	--	--
Means	453	2.34	0.35	0.19	1.81
Engelsman	320	3.01	0.42	0.30	2.29
Representative	453	2.34	0.35	0.19	1.81

Because the Means publication provides a relatively consistent set of data for this and other operations, and also because exactly the same sorts of adjustments are used for other operations, these adjustments are described in detail here. To apply an inch-and-a-half-thick layer of asphalt, Means calls

for a crew consisting of one foreman at \$22.25 per hour (billing cost), seven building laborers at \$19.40 each, and two medium-equipment operators at \$24.95. The total hourly labor cost comes to \$158.05. The equipment required includes a paving machine which costs \$68.05 per hour and a ten-ton roller at \$20.51 per hour, bringing the total equipment cost to \$88.56 per hour.

Multiplying the hourly production by the cost per sq yard gives the total hourly cost:

$$\frac{3300 \text{ yd}^2/\text{day}}{8 \text{ hr/day}} \times \$2.87/\text{yd}^2 = \$1183.88/\text{hr}$$

Subtracting the hourly labor and equipment charge from this amount gives the hourly material cost:

$$\$1183.88 - (\$158.05 + \$88.56) = \$937.27$$

Next, it is necessary to calculate the effective application rate in terms of sq meters per hour. There are three adjustments to be made. One is to convert from sq yards to sq meters. The second is to adjust for one hour per shift lost to radiation control measures. The third adjustment is to convert the figures to reflect a pavement thickness of 1.0 inch rather than 1.5 inches. The method for dealing with this last adjustment becomes apparent when it is noted that there is a consistent relationship between different thicknesses of pavement, the rate of application, and the cost per sq yard. Specifically, the Means data shows that doubling the pavement thickness results in halving the coverage rate and doubling the cost per unit area. Therefore, adjusting the application rate from 1.5-inch thickness to 1.0 inch requires multiplying by 1.5. Thus, the adjusted rate is

$$412.5 \text{ yd}^2/\text{hr} \times 0.836 \text{ m}^2/\text{yd}^2 \times 7/8 \text{ adj} \times 1.5 = 453 \text{ m}^2/\text{hr}$$

The material cost per unit area is not subject to the one hour in eight adjustment for radiation control. Therefore, to calculate the cost of material per sq meter at one-inch thickness, the following steps are taken to convert the material cost per hour:

$$\frac{\$937.27/\text{hr}}{412.5 \text{ yd}^2/\text{hr} \times 0.836 \text{ m}^2/\text{yd}^2} \times \frac{1.0}{1.5} = \$1.81/\text{m}^2$$

The labor and equipment costs per sq meter are calculated by simply dividing the hourly cost by the hourly production as shown:

$$\text{Labor: } \frac{\$158.05/\text{hr}}{453\ \text{m}^2/\text{hr}} = \$0.35/\text{m}^2$$

$$\text{Equipment: } \frac{\$88.56/\text{hr}}{453\ \text{m}^2/\text{hr}} = \$0.19/\text{m}^2$$

The total cost per sq meter is the sum of the three input categories, or $2.34 per sq meter.

The disparity in the rates presents the greatest difficulty in specifying representative data for this operation. The Means data was selected as representative. There are several reasons for this. One is the consistency of these data with other operations in this report. Second is the internal consistency among the input categories. Further, the total per sq meter is close to the average of all four data sources, and while the rate is somewhat lower than the average, it is one of the middle two rates reported. Moreover, the hazardous environment may make this rate more appropriate than the higher ones. Finally, this rate is consistent with the input costs per sq meter in that the associated cost per hour is reasonable for the specified inputs.

A.1.5.12 Resurface

Resurfacing asphalt pavement involves two previously described operations: planing away the top surface, followed by paving with a one-inch layer of asphalt. Paving is the more costly procedure. Adjusting the scale of the planing step to that of paving requires 453 ÷ 750 = 0.604 planing crews for every paving crew. The costs per sq meter of the combined operation are simply the sum of the costs of the separate operations. Table A.1.5.12.1 summarizes this discussion.

TABLE A.1.5.12.1. Summary of Asphalt Road Surfacing Data

Procedure	Crews	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material
Plane	0.604	750	0.91	0.35	0.56	--
Pave	1	453	2.34	0.35	0.19	1.81
Total	1	453	3.25	0.70	0.75	1.81

A.1.5.13 Medium-Thickness Asphalt Overlay

In Section A.1.5.11 the representative cost of paving asphalt with a one-inch layer of new asphalt is developed. The basis for these figures is primarily information from the Washington State Department of Transportation and the Los Angeles Department of Public Works and, to a lesser extent, Means' Building Construction Cost Data 1982. These sources are also used to develop a consistent estimate of representative costs and the rate for paving a three-inch layer of asphalt.

Data in Means (p. 47) indicate that the costs and rate of paving remain constant with the volume of pavement applied. Thus, doubling the pavement thickness will halve the application rate and double the cost per unit area. Using this relation, the costs and rate developed in Section A.1.5.11 for paving a one-inch layer can be transformed to a three-inch layer. The results are summarized in Table A.1.5.13.1.

TABLE A.1.5.13.1. Representative Data for Paving Asphalt Roads with a Three-Inch Layer of Asphalt

Rate	Cost (1982 $\$/m^2$)			
(m^2/hr)	Total	Labor	Equipment	Materials
151	7.05	1.05	0.57	5.43

An overlay of asphalt will reduce measurable radiation by shielding and preventing resuspension. Without any actual removal of radioactive particles, a three-inch layer of asphalt will reduce emitted radiation by half.

A.1.5.14 Removal and Replacement

Means' Site Work Cost Data 1982 (p. 22) lists the cost of removing asphalt pavement at $2.23 per sq yard, using one equipment operator to run both a backhoe and a hydraulic demolition hammer, plus two laborers. Labor makes up 51 percent of the costs excluding overhead, or 40 percent of total costs, while equipment accounts for 49 percent of the costs excluding overhead and profit and 39 percent of costs including overhead and profit.

The production rate for pavement removal is listed at 390 sq yards per day. With one hour per shift lost for radiation control, the average hourly production is 35 sq meters. The cost per sq meter is $3.05.

Means (p. 75) lists asphalt paving costs for thicknesses up to four inches. To standardize to a thickness of six inches, costs are adjusted upward by twice the amount that costs increased from three to four inches. Specifically, costs in 1982 dollars per sq yard are given as shown in Table A.1.5.14.1. Total cost rises by $2.00 per sq yard when thickness is increased by one inch from three to four inches. This cost per inch is applied to the increase of two inches from four to six. Thus $4.00 are added to the

TABLE A.1.5.14.1. Means Cost Data for Asphalt Paving

	Cost (1982 $)				
Thickness	Material	Labor	Equipment	Total	Total, incl. Overhead & Profit
3"	3.80	.70	.40	4.90	5.60
4"	5.10	.97	.54	6.61	7.60
6" (est)	7.70	1.31	.82	9.83	11.60

$7.60 listed for the four-inch thickness, bringing the total to $11.60 per sq yard for a six inch thickness. Other cost categories are adjusted in a similar manner. The cost per sq meter is $13.87. The production rate is estimated at 550 sq yards per day. After adjustments, this comes out to 50 sq meters per hour and a unit cost of $15.85 per sq meter.

Engelsman's 1981 Heavy Construction Cost File (p. 56) estimates the cost of removing asphalt paving over six inches thick at $0.82 per sq yard. Adjusting the daily output of 1000 sq yards by 7/8, the implied average hourly production is 91 sq meters. The adjusted cost is $1.12 per sq meter. The cost breakdown is 40 percent for labor and 60 percent for equipment.

The State of Washington Department of Transportation estimates the cost of removing six inches of asphalt pavement at $2.50 per sq yard. With adjustments, this implies a cost of $3.42 per sq meter. To replace the same surface costs $8.75 per sq yard. The same adjustments bring the cost per sq meter to $11.96.

The City of Los Angeles Department of Public Works lists a combined removal and replacement cost as $47.50 per ton of asphalt placed. They further estimate asphalt placement costs at $25.80 per ton. The difference, $21.70 per ton, is the cost of pavment removal. Since a ton of asphalt occupies 13.33 cubic feet, these costs refer to an area of 26.66 sq feet of pavement six inches thick. These figures are equivalent to $7.32 per sq yard for removal. After adjustments, this comes to $10.01 per sq meter. This figure is clearly much higher than those given previously. No explanation can be offered for this difference.

The paving cost at $25.80 comes to $11.90 per sq meter after adjustments.

The Federal Highway Administration supplied data in the form of selected tables from The Status of the Nation's Highways: Conditions and Performance (1981). As mentioned previously in the discussion of applying a thin pavement overlay, these data consist of widely varying unit costs that generally seem to be much higher than costs supplied by other sources. Further, these data apply to all road construction materials. The combined costs for removal and replacement run from $8.34 per sq meter for a rural minor collector four lanes

or more wide on flat terrain, to $112.49 per sq meter for two lanes' width of an urban freeway in a built-up area. These figures have been adjusted to account for radiation control measures.

The representative unit cost of removal is calculated as the average of the asphalt removal costs, excluding those for the Los Angeles Public Works Department. All of the replacement costs are averaged to get the representative cost. Representative input costs are based on the percentage of total costs for the inputs as reported by Means and Engelsman. These percentages are averaged between the two sources, and then the average percentage is applied to the corresponding representative total cost. Representative production rates are averages of the reported rates. The representative cost data for concrete surfaces are all calculated as averages. The rate for the combined removal and replacement operation is set at 71 sq meters per hour, the rate of the more costly replacement procedure. This implies that there will be 71/63 = 1.13 removal crews per replacement crew. These data are summarized in Table A.1.5.14.2.

TABLE A.1.5.14.2. Summary of Pavement Removal and Reconstruction Cost and Productivity Data

Source Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$)			
		Total	Labor	Equipment	Materials
		ASPHALT SURFACES			
Means					
Removal	35	3.05	1.22	1.83	--
Replacement	50	15.85	2.06	3.17	10.62
Total		18.90	3.28	5.00	10.62
Englesman					
Removal	91	1.12	0.45	0.67	--
Replacement	91	11.78	1.65	0.94	9.19
Total		12.90	2.10	1.61	9.19
Wash. Dept. of Trans.					
Removal	--	3.42	--	--	--
Replacement	--	11.96	--	--	--
Total	--	15.38	--	--	--
L.A. Pub. Works					
Removal	--	10.01	--	--	--
Replacement	--	11.90	--	--	--
Total	--	21.91	--	--	--
Representative					
Removal	63	2.53	1.01	1.52	--
Replacement	71	12.87	1.67	1.80	9.40
Total	71	15.40	2.68	3.32	9.40

A.1.6 Other Asphalt Surfaces

"Other asphalt" refers to paved areas of smaller size than roads or large parking lots. Other asphalt surfaces are more likely to have restricted access than asphalt roads. Examples of other asphalt surfaces include driveways, carports, sidewalks, and patios. Many of the operations described for asphalt roads are also applicable to other asphalt areas. However, because these other asphalt surfaces are smaller and have restricted access, production rates are likely to be slower. This could result from such things as the inability to use large-scale equipment. Therefore, where better data are lacking, costs for operations on other asphalt are estimated by doubling the labor, equipment, and fuel costs per sq meter and halving the production rate for the corresponding operation on asphalt roads. In some cases, independent cost and rate estimates for operations on other asphalt are developed in the corresponding sections on asphalt roads.

A.1.7 Concrete Streets, Roads and Parking

Most of the operations for concrete roads are the same as for asphalt roads. Therefore, for many of the operations on concrete roads, the reader is directed to the section describing the corresponding operation on asphalt roads. Where significant differences exist, they are noted.

A.1.7.1 Vacuum

See Section A.1.5.1.

A.1.7.2 Low-Pressure Water Wash

See Section A.1.5.2.

A.1.7.3 High-Pressure Water Wash

See Section A.1.5.3.

A.1.7.4 Very High-Pressure Water Wash

See Section A.1.5.4.

A.1.7.5 Foam

See Section A.1.5.5.

A.1.7.6 Strippable Coating

See Section A.1.5.6.

A.1.7.7 Planing

Planing is described in Section A.1.5.7. According to the Los Angeles Department of Public Works, planing concrete takes about 20% more time than

planing asphalt. Therefore, the representative asphalt planing data from Section A.1.5.7 are adjusted to account for this slower rate, holding hourly costs constant. The rate for planing concrete is 625 sq meters per hour. The total cost is $1.09 per sq meter, of which labor accounts for $0.42 and equipment accounts for $0.67.

A.1.7.8 Tack Coat

See Section A.1.5.8.

A.1.7.9 Sealer

See Section A.1.5.9.

A.1.7.10 Road Oil

See Section A.1.5.10.

A.1.7.11 Thin Asphalt Overlay

Currently, asphalt is the preferred paving material over concrete in most situations. While a new asphalt surface on an existing asphalt base generally poses no particular difficulties, asphalt surfacing on a concrete base could. Because concrete is rigid, cracked concrete can rock as the vehicle load moves across it. This rocking can result in the breaking up of an asphalt coating unless the coating is fairly thick. For this reason, the Los Angeles Public Works Department never uses less than two inches of asphalt on a concrete base. On the other hand, the State of Washington Department of Transportation reported that they maintained their minimum thickness of an asphalt overlay on concrete at 1 to 1.5 inches, the same as over an asphalt base.

In this report it is assumed that a minimum of two inches of asphalt pavement would be required when laid over a concrete base. As mentioned in Section A.1.5.11, data in Means' Building Construction Cost Data 1982 show that doubling the pavement thickness results in doubling the cost per sq meter and halving the coverage rate. The costs and rate for paving over concrete are estimated using this relationship applied to the representative data for paving over asphalt. Therefore, the rate is 227 sq meters per hour and the total cost per sq meter is $4.70. This total breaks down into $0.70 for labor, $0.38 for equipment, and $3.62 for material.

A.1.7.12 Resurface

As with resurfacing asphalt (see Section A.1.5.12), resurfacing concrete involves planing followed by an application of a thin layer of asphalt. The only differences between resurfacing concrete and asphalt are that planing concrete takes longer than planing asphalt and that a thicker pavement layer is necessary on concrete. Resurfacing as a single operation therefore amounts to combining planing and paving. This is shown in Table A.1.7.12.1. The rate for the combined operation is set at that of the more costly step, paving. This means that 227 ÷ 625 = 0.363 planing crews would be used for every paving crew.

TABLE A.1.7.12.1. Summary of Concrete Road Resurfacing Data

Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Material
Plane	625	1.09	0.42	0.67	--
Pave	227	4.70	0.70	0.38	3.62
Total	227	5.79	1.12	1.05	3.62

A.1.7.13 Medium-Thickness Asphalt Overlay

See Section A.1.5.13.

A.1.7.14 Removal and Replacement

See Section A.1.5.14 for a general discussion of removal and replacement of pavement. The data collected and the representative data are shown in Table A.1.7.14.1.

TABLE A.1.7.14.1. Summary of Pavement Removal and Reconstruction Cost and Productivity Data

Source Procedure	Rate (m^2/hr)	Cost (1982 $/$m^2$) Total	Labor	Equipment	Materials
CONCRETE SURFACES					
Means					
Removal	23	4.66	1.86	2.80	--
Replacement	182	18.93	0.95	3.03	14.95
Total	134	23.59	2.81	5.83	14.95
Englesman					
Removal	69	2.40	1.22	1.18	--
Replacement	160	13.25	0.93	0.53	11.79
Total	144	15.65	2.15	1.71	11.79
Representative					
Removal	46	3.53	1.54	1.99	--
Replacement	171	16.09	0.94	1.78	13.37
Total	171	19.62	2.48	3.77	13.37

A.1.8 Other Concrete Surfaces

The relationship between other concrete surfaces and concrete roads is the same as that between other asphalt and asphalt roads, as described in Section A.1.6. Moreover, cost estimates for other concrete surfaces are handled in the same manner as described in Section A.1.6.