2 Cost of Owning and Operating Construction Equipment

2.1 INTRODUCTION

A thorough understanding of both estimated and actual costs of operating and owning equipment drives profitable equipment management. This chapter develops that understanding in detail and helps the reader understand the calculations that go into determining the fundamental costs for an equipment-intensive project.

Plant, equipment, and tools used in construction operations are priced in the following three categories in the estimate:

1. *Small tools and consumables*: Hand tools up to a certain value together with blades, drill bits, and other consumables used in the project are priced as a percentage of the total labor price of the estimate.
2. *Equipment usually shared by a number of work activities*: These kinds of equipment items are kept at the site over a period of time and used in the work in progress.
3. *Equipment used for specific tasks*: These are capital items and used in projects such as digging trench or hoisting material into specified slots. This equipment is priced directly against the take-off quantities for the Project it is to be used on. The equipment is not kept on-site for extended periods like those in the previous classification, but the equipment is shipped to the site, used for its particular task, and then immediately shipped back to its original location. Excavation equipment, cranes, hoisting equipment, highly specialized, and costly items such as concrete saws fall into this category.

This chapter's focus is on estimating the cost of owning and operating construction equipment of the third category. For contractors in the heavy civil construction industry, the cost of owning and operating equipment is a key part of doing business in a profitable manner. Failing to properly estimate equipment cost has led many contractors into hardship. Without knowing the actual equipment ownership costs, contractors might report higher-than-justified paper profits due to inaccurate accounting practices that do not factor the cost of idle equipment into the company's overall profit picture. Then at the end of the year, they find that they had not accounted for the incurred costs of idle equipment impacting the actual profit margin. This situation is particularly dangerous in a declining market where the contractor's annual volume is lower than normal due to fewer projects getting executed. It can also happen in growing companies that have not yet developed a mature database to estimate actual equipment costs.

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Total equipment costs comprise two separate components: ownership costs and operating costs. Except for the one-time initial capital cost of purchasing the machine, ownership costs are fixed costs that are incurred each year, regardless of whether the equipment is operated or idle. Operating costs are the costs incurred only when the equipment is used. Each cost has different characteristics of its own and is calculated using different methods. None of these methods will give exact costs of owning and operating equipment for any given set of circumstances. This is because of the large number of variables involved, which is because of the uncertain nature of the construction business. One should consider these estimates as close approximations while calculating ownership and operating costs.

2.2 OWNERSHIP COST

Ownership costs are fixed costs. Almost all of these costs are annual in nature and include:

- Initial capital cost
- Depreciation
- Investment (or interest) cost
- Insurance cost
- Taxes
- Storage cost

2.2.1 Initial Cost

On an average, initial cost makes up about 25% of the total cost invested during the equipment's useful life [1]. This cost is incurred for incurred for getting equipment into the contractor's yard, or construction site, and having the equipment ready for operation. Many kinds of ownership and operating costs are calculated using initial cost as a basis, and normally this cost can be calculated accurately. Initial cost consists of the following items:

- Price at factory + extra equipment + sales tax
- Cost of shipping
- Cost of assembly and erection

2.2.2 Depreciation

Depreciation represents the decline in market value of a piece of equipment due to age, wear, deterioration, and obsolescence. Depreciation can result from:

- Physical deterioration occurring from wear and tear of the machine
- Economic decline or obsolescence occurring over the passage of time

In the appraisal of depreciation, some factors are explicit while other factors have to be estimated. Generally, the asset costs are known which include:

- *Initial cost*: The amount needed to acquire the equipment
- *Useful life*: The number of years it is expected to be of utility value
- *Salvage value*: The expected amount the asset will be sold at the end of its useful life

However, there is always some uncertainty about the exact length of the useful life of the asset and about the precise amount of salvage value, which will be realized when the asset is disposed. Any assessment of depreciation, therefore, requires these values to be estimated. Among many depreciation methods, the straight-line method, double-declining balance

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method, and sum-of-years'-digits method are the most commonly used in the construction equipment industry [2] and will be discussed below. At this point, it is important to state that the term depreciation as used in this chapter is meant to represent the change in the assets value from year to year and as a means of establishing an hourly "rental" rate for that asset. It is not meant in the same exact sense as is used in the tax code. The term "rental rate" is the rate the equipment owner charges the clients for using the equipment, i.e., the project users "rent" the equipment from its owner.

In calculating depreciation, the initial cost should include the costs of delivery and start-up, including transportation, sales tax, and initial assembly. The equipment life used in calculating depreciation should correspond to the equipment's expected economic or useful life. The reader can consult the references at the end of this chapter for a more thorough discussion of the intricacies of depreciation.

2.2.2.1 Straight-Line Depreciation

Straight-line depreciation is the simplest to understand as it makes the basic assumption that the equipment will lose the same amount of value in every year of its useful life until it reaches its salvage value. The depreciation in a given year can be expressed by the following equation:

$$D_n = \frac{\text{IC} - S - \text{TC}}{N} \tag{2.1}$$

where D_n is the depreciation in year n, IC the initial cost (\$), S the salvage value (\$), TC the tire and track costs (\$), N the useful life (years), and $D_1 = D_2 = \cdots = D_n$.

2.2.2.2 Sum-of-Years'-Digits Depreciation

The sum-of-years'-digits depreciation method tries to model depreciation assuming that it is not a straight line. The actual market value of a piece of equipment after 1 year is less than the amount predicted by the straight-line method. Thus, this is an accelerated depreciation method and models more annual depreciation in the early years of a machine's life and less in its later years. The calculation is straightforward and done using the following equation:

$$D_n = \frac{(\text{year "}n\text{" digit})}{1 + 2 + \cdots + N}(\text{IC} - S - \text{TC}) \tag{2.2}$$

where D_n is the depreciation in year n, year n digit is the reverse order: n if solving for D_1 or 1 if solving for D_n, IC the initial cost (\$), S the salvage value (\$), TC the tire and track costs (\$), and N the useful life (years).

2.2.2.3 Double-Declining Balance Depreciation

The double-declining balance depreciation is another method for calculating an accelerated depreciation rate. It produces more depreciation in the early years of a machine's useful life than the sum-of-years'-digits depreciation method. This is done by depreciating the "book value" of the equipment rather than just its initial cost. The book value in the second year is merely the initial cost minus the depreciation in the first year. Then the book value in the next year is merely the book value of the second year minus the depreciation in the second year, and so on until the book value reaches the salvage value. The estimator has to be careful when using this method and ensure that the book value never drops below the salvage value:

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$$D_n = \frac{2}{N}(\mathrm{BV}_{n-1} - \mathrm{TC}) \tag{2.3}$$

where D_n is the depreciation in year n, TC the tire and track costs (\$), N the useful life (years), BV_{n-1} the book value at the end of the previous year, and $\mathrm{BV}_{n-1} \geq S$.

Example 2.1 Compare the depreciation in each year of the equipment's useful life for each of the above depreciation methods for the following wheeled front-end bucket loader:

- *Initial cost*: \$148,000 includes delivery and other costs
- *Tire cost*: \$16,000
- *Useful life*: 7 years
- *Salvage value*: \$18,000.

A sample calculation for each method will be demonstrated and the results are shown in Table 2.1.

Straight-line method: From Equation 2.1, the depreciation in the first year D_1 is equal to the depreciation in all the years of the loader's useful life:

$$D_1 = \frac{\$148{,}000 - \$18{,}000 - \$16{,}000}{7\,\text{years}} = \$16{,}286/\text{year}$$

Sum-of-years'-digits method: From Equation 2.2, the depreciation in the first year D_1 and the second year D_2 are:

$$D_1 = \frac{7}{1+2+3+4+5+6+7}(\$148{,}000 - \$18{,}000 - \$16{,}000) = \$28{,}500$$

$$D_2 = \frac{6}{1+2+3+4+5+6+7}(\$148{,}000 - \$18{,}000 - \$16{,}000) = \$24{,}429$$

Double-declining balance method: From Equation 2.2, the depreciation in the first year D_1 is

$$D_1 = \frac{2}{7}(\$148{,}000 - \$16{,}000) = \$37{,}714$$

and the "book value" at the end of Year 1 = \$148,000 − \$16,000 − \$37,714 = \$94,286.

However, in Year 6, this calculation would give an annual depreciation of \$7,012 which when subtracted from the book value at the end of Year 5 gives a book value of \$17,531 for Year 6. This is less than the salvage value of \$18,000; therefore, the depreciation in Year 6 is

TABLE 2.1
Depreciation Method Comparison for Wheeled Front-End Loader

	Year						
Method	**1**	**2**	**3**	**4**	**5**	**6**	**7**
SL (D_n)	\$16,286	\$16,286	\$16,286	\$16,286	\$16,286	\$16,286	\$16,286
SOYD (D_n)	\$28,500	\$24,429	\$20,357	\$16,286	\$12,214	\$8,143	\$4,071
DDB (D_n)	\$37,714	\$26,939	\$19,242	\$13,744	\$9,817	\$6,543	\$0
DDB (BV)	\$94,286	\$67,347	\$48,105	\$34,361	\$24,543	\$18,000	\$18,000

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reduced to the amount that would bring the book value to be equal to the salvage value or \$6,543, and the depreciation in Year 7 is taken as zero, which means that the machine was fully depreciated by the end of Year 6.

Selecting a depreciation method for computing ownership cost is a business policy decision. Thus, this book will method any particular. The U.S. Internal Revenue Service publishes a guide that details the allowable depreciation for tax purposes, and many companies choose to follow this in computing the ownership costs. As stated before, the purpose of calculating the depreciation amount is to arrive at an hourly rental rate so that the estimator can use this figure out the cost of equipment-intensive project features of work, and not to develop an accounting system that serves to alter a given organization's tax liabilities. While this obviously impacts a company's ultimate profitability, this book separates tax costs from tax consequences, leaving the tax consequences of business policy decisions for the accountants rather than the estimators.

2.2.3 Investment (or Interest) Cost

Investment (or interest) cost represents the annual cost (converted into an hourly cost) of capital invested in a machine [2]. If borrowed funds are utilized for purchasing a piece of equipment, the equipment cost is simply the interest charged on these funds. However, if the equipment is purchased with company assets, an interest rate that is equal to the rate of return on company investment should be charged. Therefore, investment cost is computed as the product of interest rate multiplied by the value of the equipment, which is then converted into cost per hour of operation.

The average annual cost of interest should be based on the average value of the equipment during its useful life. The average value of equipment may be determined from the following equation:

$$P = \frac{\mathrm{IC}(n+1)}{2} \tag{2.4}$$

where IC is the total initial cost, P the average value, and n the useful life (years).

This equation assumes that a unit of equipment will have no salvage value at the end of its useful life. If a unit of equipment has salvage value when it is disposed of, the average value during its life can be obtained from the following equation:

$$P = \frac{\mathrm{IC}(n+1) + S(n-1)}{2n} \tag{2.5}$$

where IC is the total initial cost, P the average value, S the salvage value, and n the useful life (years).

Example 2.2 Consider a unit of equipment costing \$50,000 with an estimated salvage value of \$15,000 after 5 years. Using Equation (2.5), the average value is

$$\begin{aligned} P &= \frac{50{,}000(5+1) + 15{,}000(5-1)}{2(5)} \\ &= \frac{300{,}000 + 60{,}000}{10} \\ &= \$36{,}000 \end{aligned}$$

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2.2.4 Insurance Tax and Storage Costs

Insurance cost represents the cost incurred due to fire, theft, accident, and liability insurance for the equipment. Tax cost represents the cost of property tax and licenses for the equipment. Storage cost includes the cost of rent and maintenance for equipment storage yards, the wages of guards and employees involved in moving equipment in and out of storage, and associated direct overhead.

The cost of insurance and tax for each item of equipment may be known on an annual basis. In this case, this cost is simply divided by the hours of operation during the year to yield the cost per hour for these items. Storage costs are usually obtained on an annual basis for the entire equipment fleet. Insurance and tax costs may also be known on a fleet basis. It is then necessary to prorate these costs to each item. This is usually done by converting the total annual cost into a percentage rate, then dividing these costs by the total value of the equipment fleet. By doing so, the rate for insurance, tax, and storage may simply be added to the investment cost rate for calculating the total annual cost of investment, insurance, tax, and storage [2].

The average rates for interest, insurance, tax, and storage found in the literature are listed in Table 2.2 [2–5]. These rates will vary according to related factors such as the type of equipment and location of the job site.

2.3 TOTAL OWNERSHIP COST

Total equipment ownership cost is calculated as the sum of depreciation, investment cost, insurance cost, tax, and storage cost. As mentioned earlier, the elements of ownership cost are often known on an annual cost basis. However, while the individual elements of ownership cost are calculated on an annual cost basis or on an hourly basis, total ownership cost should be expressed as an hourly cost.

After all elements of ownership costs have been calculated, they can be summed up to yield total ownership cost per hour of operation. Although this cost may be used for estimating and for charging equipment cost to projects, it does not include job overhead or profit. Therefore, if the equipment is to be rented to others, overhead and profit should be included to obtain an hourly rental rate.

Example 2.3 Calculate the hourly ownership cost for the second year of operation of a 465 hp twin-engine scraper. This equipment will be operated 8 h/day and 250 days/year in average conditions. Use the sum-of-years'-digits method of depreciation as the following information:

- *Initial cost*: $186,000
- *Tire cost*: $14,000
- *Estimated life*: 5 years

TABLE 2.2
Average Rates for Investment Costs

Item	Average Value (%)
Interest	3–9
Tax	2–5
Insurance	1–3
Storage	0.5–1.5

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- *Salvage value*: \$22,000
- *Interest on the investment*: 8%
- *Insurance*: 1.5%
- *Taxes*: 3%
- *Storage*: 0.5%
- *Fuel price*: \$2.00/gal
- *Operator's wages*: \$24.60/h

$$\text{Depreciation in the second year} = \frac{4}{15}(186{,}000 - 22{,}000 - 14{,}000) = \$40{,}000$$
$$= \frac{40{,}000}{8(250)} = \$20.00/\text{h}$$

Investment cost, tax, insurance, and storage cost:

$$\text{Cost rate} = \text{investment} + \text{tax, insurance, and storage} = 8 + 3 + 1.5 + 0.5 = 13\%$$

$$\text{Average investment} = \frac{186{,}000 \pm 22{,}000}{2(5)} = \$20{,}800$$

$$\text{Investment, tax, insurance, and storage} = \frac{84{,}000(0.18)}{2000} = \$7.56/\text{h}$$

$$\text{Total ownership cost} = 16.53 + 7.56 = \$24.09/\text{h}$$

2.4 COST OF OPERATING CONSTRUCTION EQUIPMENT

Operating costs of the construction equipment, which represent a significant cost category and should not be overlooked, are the costs associated with the operation of a piece of equipment. They are incurred only when the equipment is actually used. The operating costs of the equipment are also called "variable" costs because they depend on several factors, such as the number of operating hours, the types of equipment used, and the location and working condition of the operation.

The operating costs vary with the amount of equipment used and job-operating conditions. The best basis for estimating the cost of operating construction equipment is the use of historical data from the experience of similar equipment under similar conditions. If such data is not available, recommendations from the equipment manufacturer could be used.

2.4.1 Maintenance and Repair Cost

The cost of maintenance and repairs usually constitutes the largest amount of operating expense for the construction equipment. Construction operations can subject equipment to considerable wear and tear, but the amount of wear varies enormously between the different items of the equipment used and between different job conditions. Generally, the maintenance and repair costs get higher as the equipment gets older. Equipment owners will agree that

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TABLE 2.3
Range of Typical Lifetime Repair Costs from the Literature [2,5,6]

	Initial Cost without Tires (%)		
	Operating Conditions		
Equipment Type	**Favorable**	**Average**	**Unfavorable**
Crane	40–45	50–55	60–70
Excavator crawler	50–60	70–80	90–95
Excavator wheel	75	80	85
Loader track	80–85	90	100–105
Loader wheel	50–55	60–65	75
Motor grader	45–50	50–55	55–60
Scraper	85	90–95	105
Tractor crawler	85	90	95
Tractor wheel	50–55	60–65	75
Truck, off-highway	70–75	80–85	90–95

good maintenance, including periodic wear measurement, timely attention to recommended service and daily cleaning when conditions warrant it, can extend the life of the equipment and actually reduce the operating costs by minimizing the effects of adverse conditions. All items of plant and equipment used by construction contractors will require maintenance and probably also require repairs during the course of their useful life. The contractor who owns the equipment usually sets up facilities for maintenance and engages the workers qualified to perform the necessary maintenance operations on the equipment.

The annual cost of maintenance and repairs may be expressed as a percentage of the annual cost of depreciation or it may be expressed independently of depreciation. The hourly cost of maintenance and repair can be obtained by dividing the annual cost by its operating hours per year. The hourly repair cost during a particular year can be estimated by using the following formula [2]:

$$\text{Hourly repair cost} = \frac{\text{year digit}}{\text{sum-of-years'-digits}} \times \frac{\text{lifetime repair cost}}{\text{hours operated}} \tag{2.6}$$

The lifetime repair cost is usually estimated as a percentage of the equipment's initial cost deducting the cost of tires. It is adjusted by the operating condition factor obtained from Table 2.3.

Example 2.4 Estimate the hourly repair cost of the scraper in Example 2.3 for the second year of operation. The initial cost of the scraper is \$186,000, tire cost \$14,000, and its useful life is 5 years. Assume average operating condition and 2000 h of operation per year.

$$\text{Lifetime repair cost factor} = 0.90$$
$$\text{Lifetime repair cost} = 0.90(186{,}000 - 14{,}000) = \$154{,}800$$
$$\text{Hourly repair cost} = \frac{2}{15}\left(\frac{154{,}800}{2000}\right) = \$10.32/\text{h}$$

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TABLE 2.4
Range of Typical Tire Life from the Literature [2,5]

	Average Tire Life (h)		
	Operating Conditions		
Equipment Type	**Favorable**	**Average**	**Unfavorable**
Loader wheel	3200–4000	2100–3500	1300–2500
Motor grader	5000	3200	1900
Scraper single engine	4000–4600	3000–3300	2500
Scraper twin engine	3600–4000	3000	2300–2500
Scraper elevating	3600	2700	2100–2250
Tractor wheel	3200–4000	2100–3000	1300–2500
Truck, off-highway	3500–4000	2100–3500	1100–2500

2.4.2 Tire Cost

The tire cost represents the cost of tire repair and replacement. Because the life expectancy of rubber tires is generally far less than the life of the equipment on which they are used on, the depreciation rate of tires will be quite different from the depreciation rate of the rest of the vehicle. The repair and maintenance cost of tires as a percentage of their depreciation will also be different from the percentage associated with the repair and maintenance of the vehicle. The best source of information in estimating tire life is the historical data obtained under similar operating conditions. Table 2.4 lists the typical ranges of tire life found in the most recent literature on the subject for various types of equipment.

Tire repair cost can add about 15% to tire replacement cost. So, the following equation may be used to estimate tire repair and replacement cost:

$$\text{Tire repair and replacement costs} = 1.15 \times \frac{\text{cost of a set of tires (\$)}}{\text{expected tire life (h)}} \tag{2.7}$$

2.4.3 Consumable Costs

Consumables are the items required for the operation of a piece of equipment that literally gets consumed in the course of its operation. These include, but are not limited to, fuel, lubricants, and other petroleum products. They also include filters, hoses, strainers, and other small parts and items that are used during the operation of the equipment.

2.4.3.1 Fuel Cost

Fuel consumption is incurred when the equipment is operated. When operating under standard conditions, a gasoline engine will consume approximately 0.06 gal of fuel per flywheel horsepower hour (fwhp-h), while a diesel engine will consume approximately 0.04 gal/fwhp-h. A horsepower hour is a measure of the work performed by an engine.

The hourly cost of fuel is estimated by multiplying the hourly fuel consumption by the unit cost of fuel. The amount of fuel consumed by the equipment can be obtained from the historical data. When the historical data is not available, Table 2.5 gives approximate fuel consumption (gal/h) for major types of equipment.

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TABLE 2.5
Average Fuel Consumption Factors (gal/h/hp) [2,5]

	Working Conditions (gal/h/hp)		
Equipment Type	**Favorable**	**Average**	**Unfavorable**
Loader track	0.030–0.034	0.040–0.042	0.046–0.051
Loader wheel	0.020–0.024	0.027–0.036	0.031–0.047
Motor grader	0.022–0.025	0.029–0.035	0.036–0.047
Scraper single engine	0.023–0.026	0.029–0.035	0.034–0.044
Scraper twin engine	0.026–0.027	0.031–0.035	0.037–0.044
Tractor crawler	0.028–0.342	0.037–0.399	0.046–0.456
Tractor wheel	0.020–0.028	0.026–0.038	0.031–0.052
Truck, off-highway	0.017–0.029	0.023–0.037	0.029–0.046
Truck, on-highway	0.014–0.029	0.020–0.037	0.026–0.046

Example 2.5 Calculate the average hourly fuel consumption and hourly fuel cost for a twin-engine scraper in Example 2.3. It has a diesel engine rated at 465 hp and fuel cost \$2.00/gal. During a cycle of 20 s, the engine may be operated at full power, while filling the bowl in tough ground requires 5 s. During the balance of the cycle, the engine will use no more than 50% of its rated power. Also, the scraper will operate about 45 min/h on average. For this condition, the approximate amount of fuel consummated during 1 h is determined as follows:

Rated power: 465 hp
Engine factor: 0.5
Filling the bowl, 5 s/20 s cycle $=$ 0.250
Rest of cycle, $15/20 \times 0.5 = 0.375$
Total cycle $=$ 0.625
Time factor, 45 min/60 min $=$ 0.75
Operating factor, $0.625 \times 0.75 = 0.47$
From Table 2.5: use "unfavorable" fuel consumption factor $=$ 0.040
Fuel consumed per hour: $0.47(465)(0.040) = 8.74$ gal
Hourly fuel cost: 8.74 gal/h (\$2.00/gal) $=$ \$17.48/h.

2.4.3.2 Lubricating Oil Cost

The quantity of oil required by an engine per change will include the amount added during the change plus the make-up oil between changes. It will vary with the engine size, the capacity of crankcase, the condition of the piston rings, and the number of hours between oil changes. It is a common practice to change oil every 100 to 200 h [6].

The quantity of oil required can be estimated by using the following formula [6]:

$$q = \frac{0.006(\text{hp})(f)}{7.4} + \frac{c}{t} \tag{2.8}$$

where q is the quantity consumed (gal/h), hp the rated horsepower of engine, c the capacity of crankcase (gal), f the operating factor, t the number of hours between changes, the consumption rate 0.006 lbs/hp-h, and the conversion factor 7.4 lbs/gal.

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The consumption data or the average cost factors for oil, lubricants, and filters for their equipment under average conditions are available from the equipment manufacturers.

2.4.4 Mobilization and Demobilization Cost

This is the cost of moving the equipment from one job site to another. It is often overlooked because of the assumption that the previous job would have already paid for it. Regardless of these calculations, the costs of equipment mobilization and demobilization can be large and are always important items in any job where substantial amounts of equipment are used. These costs include freight charges (other than the initial purchase), unloading cost, assembly or erection cost (if required), highway permits, duties, and special freight costs (remote or emergency). For a $3-million earthmoving job, it is not unusual to have a budget from $100,000 to $150,000 for move-in and move-out expenses. The hourly cost can be obtained from the total cost divided by the operating hours. Some public agencies cap the maximum amount of mobilization that will be paid before the project is finished. In these instances, the estimator must check the actual costs of mobilization against the cap. If the cap is exceeded, the unrecovered amount must be allocated to other pay items to ensure that the entire cost of mobilization is recovered.

2.4.5 Equipment Operator Cost

Operator's wages are usually added as a separate item and added to other calculated operating costs. They should include overtime or premium charges, workmen's compensation insurance, social security taxes, bonus, and fringe benefits in the hourly wage figure. Care must be taken by the companies that operate in more than one state or that work for federal agencies, state agencies and private owners. The federal government requires that prevailing scale (union scale) of wages be paid to workers on its project regardless of whether the state is a union state or not. This is a requirement of the Davis Bacon Act [7] and most federal contracts will contain a section in the general conditions that details the wage rates that are applicable to each trade on the project.

2.4.6 Special Items Cost

The cost of replacing high-wear items, such as dozer, grader, and scraper blade cutting and end bits, as well as ripper tips, shanks, and shank protectors, should be calculated as a separate item of the operating cost. As usual, unit cost is divided by the expected life to yield cost per hour.

2.5 METHODS OF CALCULATING OWNERSHIP AND OPERATING COST

The most common methods available are the caterpillar method, Association of General Contractors of America (AGC) method, the Equipment Guide Book (EGB) method, the dataquest method, the Corps of Engineers method, and the Peurifoy method. Each method is described below and three examples are given in Appendix A.

2.5.1 Caterpillar Method

The Caterpillar method is based on the following principles [8]:

1. No prices for any items are provided. For reliable estimates, these must always be obtained locally.

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2. Calculations are based on the complete machine. Separate estimates are not necessary for the basic machine, dozer, control, etc.
3. The multiplier factors provided will work equally well in any currency expressed in decimals.
4. Because of different standards of comparison, what may seem a severe application to one machine owner may appear only average to another. Therefore, in order to better describe machine use, the operating conditions and applications are defined in zones.

2.5.1.1 Ownership Costs

Ownership costs are calculated as a sum of costs incurred due to depreciation, interest, insurance, and taxes. Usually depreciation is done to zero value with the straight-line method, which is not based on tax consideration, but resale or residual value at replacement may be included for depreciation or tax incentive purposes. Service life of several types of equipment is given in the *Caterpillar Performance Handbook* [8]. Acquisition or delivered costs should include costs due to freight, sales tax, delivery, and installation. On rubber-tired machines, tires are considered as a wear item and covered as an operating expense. Tire cost is subtracted from the delivered price. The delivered price less the estimated residual value results in the value to be recovered through work, divided by the total usage hours, giving the hourly cost to project the asset's value. The interest on capital used to purchase a machine must be considered, whether the machine is purchased outright or financed. Insurance cost and property taxes can be calculated in one of the two ways.

2.5.1.2 Operating Costs

Operating costs are based on charts and tables in the handbook. They are broken down as follows:

1. Fuel
2. Filter, oil, and grease (FOG) costs
3. Tires
4. Repairs
5. Special items
6. Operator's wages

The factors for fuel, FOG, tires, and repairs costs can be obtained for each model from tables and charts given in the *Caterpillar Performance Handbook* [8]. Tire costs can be estimated from previous records or from local prices. Repairs are estimated on the basis of a repair factor that depends on the type, employment, and capital cost of the machine. The operator's wages are the local wages plus the fringe benefits. Table 2.6 is an example of the application of this method for a truck-mounted crane.

2.5.2 Corps of Engineers Method

This method is often considered as the most sophisticated method for calculating equipment ownership costs because it not only covers economic items but also includes geographic conditions. This method generally provides hourly use rates for construction equipment based on a standard 40-h workweek. The total hourly use rates include all costs of owning and operating equipment except operator wages and overhead expenses. The ownership portion of the rate consists of allowances for depreciation and costs of facilities capital cost of money (FCCM). Operating costs include allowances for fuel, filter, oil, grease, servicing the equipment, repair and maintenance, and tire wear and tire repair [9].

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TABLE 2.6
Caterpillar Method Example for 150 Ton Truck Crane

Truck-mounted crane 150 ton w/260′	Estimated annual use in hours = 1590 h	Tires drive = $7040
Lattice boom	Total expected use in hours = 20,000 h	Fuel cost = $2.00/gal
Equipment horsepower: 207;	Useful life = 20,000/1590 = 12.58 years	Sales tax = 8.7%
carrier horsepower 430	Tires front = $3520	Factor = factor taken from the reference manual [4]
Average conditions of use		

Calculation of Depreciation Value

1. Delivered price (including taxes, freight, and installation)		
List price		= $1,197,389.00
Discount: at 7.5%	Less	= $89,804.00
	Subtotal	= $1,107,585.00
Sales tax: at 8.7%		= $96,360.00
	Subtotal	= $1,203,945.00
Freight: 1913 cwt ($3.08/cwt)		= $5892.00
		= $1,203,837.00
2. Less tire replacement costs		
Front: $3520		
Drive: $7040		= $10,560.00
3. Delivered price less tires		= $1,193,277.00
4. Net value for depreciation		= $1,193,277.00

Ownership Cost

5. Depreciation = [net value]/[depreciation period in hours] = $1,193,277.00/20,000	= $59.66
6. Interest, insurance, taxes: interest = 6.75%; insurance = 3%; taxes = 2%	
Interest: $\frac{[(12.58 \pm 1)/2(12.58)](1{,}193{,}277)(0.12)}{1590} = \$27.44/\text{h}$	
Insurance: $\frac{[(12.58 + 1)/2(12.58)](1{,}193{,}277)(0.03)}{1590} = \$12.20/\text{h}$	
Taxes: $\frac{[(12.58 + 1)/2(12.58)](1{,}193{,}277)(0.02)}{1590} = \$8.13/\text{h}$	
	= $47.77
7. *Total hourly ownership cost*	= $107.43

Operating Cost

8. Equipment	Factor (hp)(fuel cost per gallon)	
Equipment	(0.038)(207)(2.00) = $15.73	
Carrier	(0.006)(430)(2.00) = $5.16	
9. FOG cost		= $20.89
10. Tires		
(Replacement cost)/(Estimated life in hours) = 10,560/2500		= $4.22
11. Repairs: [Factor (delivered price less tires)]/1590 = 0.07(1,193,277)/1590		= $52.53
12. *Total hourly operating cost*		= $77.64
13. *Operators hourly wage* = $25.90		
14. *Total Ownership and Operating Cost*		= $210.97

Summary

Ownership cost per hour	= $107.43
Operating cost per hour	= $77.64
Operator wage per hour	= $25.90
Total cost per hour	= $210.97

Source: W.S Lambie, Methods of deciding overhaul or replacement. In *Handbook of Construction Management and Organization* 2nd ed., New York, Van Nostrand Reinhold Co., 1980, pp. 160–166. With permission.

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The standby hourly rate is computed from the average condition by allowing the full FCCM hourly cost plus one half of the hourly depreciation.

2.5.2.1 Ownership Costs

The Corps of Engineers method operates on the following principles:

1. Depreciation: It is calculated by using the straight-line method. The equipment cost used for depreciation calculation is subtracted by tire cost at the time the equipment was manufactured. Another cost that has to be subtracted is salvage value. It is determined from the *Handbook of New and Used Construction Equipment Values* (Green Guide) and advertisements of used equipment for sale displayed in current engineering and construction magazines [3]. The expected life span of the equipment is designated from the manufacturers' or equipment associations' recommendations.
2. FCCM: The Department of the Treasury adjusts the cost of money rate on or about 1st January and 1st July every year. This cost is computed by multiplying the cost of money rate, determined by the Secretary of the Treasury, by the average value of equipment and prorating the result over the annual operating hours. It is normally presented in terms of FCCM per hour.

It should be noted that licenses, taxes, storage, and insurance cost are not included in this computation. Instead, they are considered as indirect costs.

2.5.2.2 Operating Costs

1. *Fuel costs*: Fuel costs are calculated from records of equipment consumption, which is done in cost per gallon per hour. Fuel consumption varies depending on the machine's requirements. The fuel can be either gasoline or diesel.
2. *FOG costs*: FOG costs are usually computed as percentage of the hourly fuel costs.
3. *Maintenance and repair costs*: These are the expenses charged for parts, labor, sale taxes, and so on. Primarily, maintenance and repair costs per hour are computed by multiplying the repair factor to the new equipment cost, which is subtracted by tire cost, and divided by the number of operating hours.
4. *Hourly tire cost*: This is the current cost of new tires plus the cost of one recapping and then divided by the expected life of new tires plus the life of recapped tires. It has been determined that the recapping cost is approximately 50% of the new tire cost, and that the life of a new tire plus recapping will equal approximately 1.8 times the "useful life" of a new tire.
5. *Tire repair cost*: This cost is assumed to be 15% of the hourly tire wear cost.

Table 2.7 is an example of how this method is applied to the same piece of equipment as in Table 2.6.

2.5.3 Associated General Contractors of America (AGC) Method

This method enables the owner to calculate the ownership and operating costs to determine capital recovery [10]. Rather than dealing with the specific makes and models of the machines, the equipment is classified according to capacity or size. For example, this method computes the average annual ownership expense and the average hourly repair and maintenance expense as a percentage of the acquisition costs.

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TABLE 2.7
Corps of Engineers Method Example for 150 Ton Truck Crane

Truck-mounted crane 150 ton w/260′	Tires front = $3520
Lattice boom	Tires drive = $7040
Equipment horsepower: 207;	Fuel cost = $2.00/gal
carrier horsepower 430	Sales tax = 8.7%
Average conditions of use	Factor = factor taken from the reference manual [5]
Estimated annual use in hours = 1590 h	
Total expected use in hours = 20,000 h	
Useful life = 20,000/1590 = 12.58 years	

Factors for Calculations

1. Hourly expense calculation factors		
Economic key		= 20
Condition		= average
Discount code: B = 7.5% or S = 15% use the lower		= 0.075
Life in hours		= 20,000
Salvage value percentage		= 0.20
Fuel factor (equipment)		= 0.026
Fuel factor (carrier)		= 0.005
FOG factor		= 0.276
Tire wear factor (front)		= 0.97
Tire wear factor (drive)		= 0.78
Repair cost factor		= 0.90
Labor adjustment factor		= 0.88

Calculate Depreciation Value

2. Delivered price (at year of manufacture)		= $1,197,389.00
Discount: $1,197,389.00(0.075)	Less	= $89,804.00
	Subtotal	= $1,107,585.00
Sales tax: $1,107,585.00(0.087)		= $96,360.00
	Subtotal	= $1,203,945.00
Freight: 1913 cwt ($3.08/cwt)		= $5892.00
	Total equipment value for depreciation	= $1,203,837.00
3. Depreciation period		
20,000 h/1590 h/year		= 12.58 years

Ownership Cost

4. Depreciation	
Tire cost index (Appendix A)	
(TCI for year of equipment manufacture)/(TCI for year of equipment use)	
2373/2515 = 0.944	
Depreciation value (hourly)	
[[TEV(1 – SLV)] – [TCI(tire cost)]]/life in hours	
[[$1,203,837.00(1 – 0.20)] – [0.944($10,560)]]/20,000	= $47.90
5. Facilities capital cost of money	
Average value factor	
[(useful life − 1)(1.0 + SLV)] + 2.0]/[2(useful life)]	
[(12.58 – 1)(1.0 + 0.20)] + 2.0]/[2(12.58)] = 0.632	
FCCM	
TEV(AVF)(adjusted cost of money)/annual hours use	
$1,203,837.00(0.632)(0.034)/1590	= $16.35
6. *Total hourly ownership cost*	= $64.25

Continued

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TABLE 2.7 (Continued)
Corps of Engineers Method Example for 150 Ton Truck Crane

	Operating Cost	
7. Fuel costs	Factor (hp)(fuel cost per gallon)	
Equipment	(0.026)(207)(2.00) = $10.76/h	
Carrier	(0.005)(430)(2.00) = $4.30/h	
	Total hourly fuel cost	= $15.06
8. FOG cost: FOG factor(fuel cost)(labor adjustment factor)		
Equipment	(0.276)($10.76)(0.88) = $2.61/h	
Carrier	(0.276)($4.30)(0.88) = $1.04/h	
Total hourly FOG cost		= $3.65
9. Repair cost:		
Economic adjustment factor (Appendix E)		
Economic index for year of manufacture/economic index for year of use		
EAF = 5729/5310 = 1.079		
Repair factor: RCF(EAF)(LAF) = 0.90 (1.079)(0.88) = 0.855		
Repair cost [TEV – (TCI)(tire cost)](RF)/life		
[$1,203,837.00 – (0.944)($10,560.00)][0.855]/20,000		
	Total hourly repair cost	= $51.29
10. Tires		
Tire wear cost		
[1.5(tire cost)]/[1.8(wear factor)(tire life in hours)]		
Front tires: [1.5($3520)]/[1.8(0.97)(2500)]		= $1.21
Drive tires: [1.5($7040)]/[1.8(0.78)(2500)]		= $3.01
Total hourly tire wear cost		= $4.22
Tire repair cost		= $0.56
[1.5(tire wear cost)(LAF)]		
[1.5(4.22)(0.88)]		
Total hourly tire repair cost		
11. Sum 7–10		
12. *Total hourly operating cost*		= $69.17
13. *Operators hourly wage*		= $25.90
14. *Total Ownership and Operating Cost*		= $101.47
	Summary	
	Ownership cost per hour	= $64.25
	Operating cost per hour	= $69.17
	Operator wage and fringes per hour	= $25.90
	Total cost per hour	= $159.32

Source: From D. Atcheson. *Earthmoving Equipment Production Rates and Costs*. Venice, FL: Norseman Publishing Co., 1993. With permission.

2.5.3.1 Ownership Cost

The ownership costs considered in this method are the same as described in the Caterpillar method; however, replacement cost escalation is also considered. Depreciation is calculated by the straight-line method and includes purchase price, sales tax, freight, and erection cost, with an assumed salvage value of 10%. Average economic life in hours and average annual operating hours are shown for each size range. Replacement cost escalation of 7% is designed to augment the capital recovery and to offset inflation and machine price increase. Interest on the investment is assumed to be 7%, whereas taxes, insurance, and storage are taken as 4.5%.

2.5.3.2 Operating Costs

Maintenance and repair costs are calculated based on an hourly percentage rate times the acquisition cost. It is a level rate regardless of the age of the machine. This expense includes

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TABLE 2.8
AGC Method Example for 150 Ton Truck Crane

Truck-mounted crane 150 ton w/260′	Tires front = $3520
Lattice boom	Tires drive = $7040
Equipment horsepower: 207; carrier horsepower 430	Fuel cost = $2.00/gal
	Sales tax = 8.7%
Average conditions of use	Factor = factor taken from the reference manual [4]
Estimated annual use in hours = 1590 h	
Total expected use in hours = 20,000 h	
Useful life = 20,000/1590 = 12.58 years	

Factors for Calculations

1. Depreciation	= 15.00%
Replacement cost escalation	= 7.00%
Interest on investment	= 7.00%
Taxes, insurance, and storage	= 4.50%
Total ownership expense	= 33.50%
Repair and maintenance expense	= 19.40%
Salvage value	= 10.00%

Ownership Cost

2. Acquisition cost = (list price – tire cost)(1 – SV) = ($1,203,837.00 – $10,560)(1.0 – 0.1) = $1,083,453	
3. Average hourly Ownership expense = total ownership expense/annual use	= 33.5%/1590 h = 0.0211
Average hourly ownership cost = 0.0211($1,083,453)/100	= $228.61

Operating Cost

4. Repair and maintenance expense rate = 19.4%/1590 = 0.0122	
Average hourly repair and maintenance cost = 0.0122($1,083,453)/100	= $132.18
5. *Total hourly operating cost*	= $132.18
6. *Operators hourly wage*	= $25.90
7. *Total Ownership and Operating Cost*	= $386.69

Summary

Ownership cost per hour	= $228.61
Operating cost per hour	= $132.18
Operator wage per hour	= $25.90
Total cost per hour	= $386.69

Source: J. Douglas. Equipment costs by current methods. *Journal of Construction Division ASCE* 104(C02), 1978, 191–225. With permission.

field and shop repairs, overhaul, and replacement of tires and tracks, etc. The FOG costs and operator's wages are not considered in this method. Table 2.8 shows how the AGC method is applied to the crane example.

2.5.4 Peurifoy/Schexnayder Method

R.L. Peurifoy is considered by many to be the father of modern construction engineering. His seminal work on the subject, now in its sixth edition [6], set the standard for using rigorous engineering principles to develop rational means for developing cost estimates based on equipment fleet production rates. These methods will be discussed in detail in Chapter 5 of this book. Therefore, it is important that his particular approach to determining equipment ownership costs be included in any discussion of the subject.

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TABLE 2.9
Peurifoy/Schexnayder Method Example for 150 Ton Truck Crane

Truck-mounted crane 150 ton w/260′
Lattice boom
Equipment horsepower: 207; carrier horsepower 430

Average conditions of use
Estimated annual use in hours = 1590 h
Total expected use in hours = 20,000 h
Useful life = 20,000/1590 = 12.58 years

Tires front = $3520
Tires drive = $7040
Fuel cost = $2.00/gal
Sales tax = 8.7%
Factor = factor taken from the reference manual [6]

Factors for Calculations

1. Interest = 6.75%
   Taxes, insurance, and storage = 3.75%
   Salvage value = 20%
   Repair and maintenance = 37% depreciation cost
   Tire repair cost = 16% of straight-line depreciated tire cost
   Equipment under load 30% of the operating time
   Carrier under load 10% of the operating time
   Use 50-min productive hour

Ownership Cost

2. Initial cost = (list price – tire cost)
   From Table 2.7, line 2 = ($1,203,837.00 – $10,560) = $1,083,453
   Equivalent uniform annual cost of IC = A_{IC}=IC[$i(1+i)^n/[(1+i)^n-1]$]
   $1,083,453[0.0675(1 + 0.0675)$^{12.58}$/[(1 + 0.0675)$^{12.58}$−1]] = $143,749/year
   Equivalent uniform annual cost of SV = A_{SV}=SV[$i(1+i)^n-1$]
   0.20($1,083,453) [0.0675/[(1 + 0.0675)$^{12.58}$−1]] = $12,752/year
3. Hourly ownership cost = ($A_{IC} - A_{SV}$)/annual use

Hourly ownership cost = ($143,749/year – $12,752/year)/1590	= $82.39
Hourly taxes, insurance, and storage cost = 0.0375($1,083,453)/1590	= $22.55
Total hourly ownership cost	= $107.94

Operating Cost

4. Fuel cost = combined factor(consumption)(hp)(cost per gallon)
   Equipment load factor: Lifting = 1.00(0.30) = 0.30
   Return = 0.75(0.70) = $\frac{0.53}{0.83}$
   Carrier load factor: Running = 1.00(0.10) = 0.10
   Idle = 0.50(0.90) = $\frac{0.45}{0.55}$
   Time factor: 50 min/60 min = 0.83
   Equipment combined factor = (0.83)(0.83) = 0.69
   Equipment fuel cost = 0.69(0.03 gal/hp-h)(207 hp)($2.00/gal) = $8.57/h
   Carrier combined factor = (0.83)(0.55) = 0.46
   Carrier fuel cost = 0.46(0.04 gal/hp-h)(430 hp)($2.00/gal) = $15.82/h

Combined hourly fuel cost = 0.85(8.57) + 0.15(15.82)	= $9.66
Hourly repair and maintenance cost = 0.37($82.39/h)	= $30.48
FOG cost = use Table 2.7, line 8	= $3.65
Tire use cost = $10,560/2500 h = $4.22/h	
Tire repair cost = [$10,560/2500 h](0.16) = $0.68/h	
Total tire cost	= $4.90
5. *Total hourly operating cost*	= $48.69
6. *Operators hourly wage*	= $25.90
7. *Total Ownership and Operating Cost*	= $182.53

Summary

Ownership cost per hour	= $107.43
Operating cost per hour	= $48.69
Operator wage per hour	= $25.90
Total cost per hour	= $182.53

Source: R.L Peurifoy and C.J Schexnayder *Construction Planning, Equipment and Methods*, 6th ed. New York: Mc Graw-Hill, 2002.

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2.5.4.1 Ownership Cost

This method assumes the straight-line method for depreciation. The value of the equipment is depreciated to be zero at the end of the useful life of the equipment. The ownership costs are based on an average investment cost that is taken as 60% of the initial cost of the equipment. Usually equipment owners charge an annual fixed rate of interest against the full purchase cost of the equipment. This gives an annual interest cost, which is higher than the normal. As the cost of depreciation has already been claimed, it is more realistic to base the annual cost of investment on the average value of equipment during its useful life. This value can be obtained by taking an average of values at the beginning of each year that the equipment will be used, and this is the major difference between the Peurifoy method and the other methods. The cost of investment is taken as 15% of the average investment.

2.5.4.2 Operating Costs

As the tire life is different from that of the equipment, its costs are treated differently. The maintenance cost is taken as 50% of the annual depreciation, the fuel and the FOG costs are included, whereas the operator wages are not included. Table 2.9 finishes by showing how this method is applied to the crane example.

2.5.5 Comparison of Costs Calculated by Different Methods

It is interesting to note that each method arrives at a different hourly rental rate for the same piece of equipment. This illustrates the statement made earlier in this chapter that the method used to arrive at a number is largely a business policy decision rather than a technical decision. Table 2.10 is a summary of the four previous examples and furnishes an interesting comparison of the business decisions made by each group.

The first notable aspect is that the AGC method yields the highest rental rate. Perhaps this is because the AGC is a trade organization for construction contractors and as a result, there is a bias to be conservative in the published method for calculating an equipment rental rate. Pursuing that line of reasoning, the rate obtained by using Corps of Engineers method is the lowest. The Corps is a large public owner who may have a bias to keeping the cost of equipment on its projects as low as possible. The remaining two fall somewhere in the middle as each really has no constituency to protect. In actuality, each equipment-owning organization will have its own internal method for arriving at these rates that will satisfy the financial accounting needs of that company. These published methods are primarily used in negotiations between a owner and a contractor as a means to determine if the contractor's internal equipment rates are fair and reasonable.

2.6 SUMMARY

This chapter has provided information and data to allow the estimator who does not already have an internal method to calculate the cost of owning and operating a piece of construction

TABLE 2.10
Summary of Different Methods for Calculating Equipment Ownership and Operating Costs

Item	Caterpillar	Corps of Engineers	AGC	Peurifoy/Schexnayder
Ownership cost per hour	$107.43	$64.25	$228.61	$107.43
Operating cost per hour	$77.64	$69.17	$132.18	$48.69
Operator wage per hour	$25.90	$25.90	$25.90	$25.90
Total cost per hour	$210.97	$159.32	$386.69	$182.53

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equipment. The information can be used in several ways. First, it could be used as a reference for setting an internal standardized method for calculating equipment rental rates. Second, it could be used to perform an independent estimate of rates that are proposed for a given project to determine if they appear to be fair and reasonable. Finally, it can be used as a mutually agreed standard for calculating these types of rates during contract or change order negotiations. In any event, the estimator must strive to use the best numbers available at the time and to ensure that all the costs of both owning and operating the equipment are included in the final rate.

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