CHAPTER 4

COST OF CONSTRUCTION LABOR AND EQUIPMENT

Construction labors influence every part of a project. They operate equipment and fabricate and install materials. Detailed estimate requires the breakdown of project costs into the labor, material and equipment costs. Thus type of estimate need to have a design available to get such required details. This chapter introduces the details of estimating labor, equipment and material costs as the basis for detailed cost estimate of construction projects.

4.1 Preparing the Detailed Estimate

If a contractor chooses a project he or she can professionally and financially handle, it is worthwhile to expend all efforts to win the bid. In addition, the contractor must successfully pass a qualification screening. After the decision to bid, arrangements need to be made to pick up the contract document and prepare a detailed cost estimate. The steps listed below, in logical order, are the road map for developing a detailed estimate.

One: Review the bidding documents. Check for general conditions, specifications and all the drawings. If any discrepancies exist, record them and check with the architect or engineer. The general conditions and specifications are generally organized into the following sections: the bid, the owner/contractor agreement, bonds, alternates, general conditions, specifications, and addenda.

The bid section includes the invitation to bid, instructions to bidders, and bid forms. The invitation to bid contains a description of the nature, extent, and location of the project as well as contact information for the owner. The documents should also contain date, time and place that bids will be received; general contractor and subcontractors' prequalification requirements; date, time, and location of any pre-bid conference; availability of bidding documents with their dates, locations, and procurement costs; and bond requirements.

The owner/contractor agreement section is most often a "standard" document that formalizes the construction contract price and construction duration. It should also list progress payments retained, percentage of completed work value, acceptance conditions, and final payment constraints.

The bond section should include bid bond and performance bond forms and requirements. Bonds are written documents that describe the conditions and obligations related to the owner/contractor agreement. A bid bond certifies that if a contractor is awarded the bid within the time specified in the invitation to bid, the contractor will enter into the contract and will provide all other required bonds in a timely manner. A performance bond guarantees the owner that within agreement limits the contractor will perform all work in accordance with the contracting document. Labor and material bonds guarantee to the owner that the contractor will pay in a timely fashion for supplied materials used by all the subcontractors related to the project.

Two: Review the drawings to visualize the building size, height, shape, function, basements, and so on. Start with floor plans, cross-sections, exterior finish system, and the roof. Note all unusual construction procedures, building systems, and materials that have been specified.

Three: Review structural drawings to get acquainted with specified systems: reinforced concrete, structural steel, masonry, wood, or combinations. Find out which pieces of heavy construction equipment will be needed for erection and for how long. Pay attention to various wall sections, materials and prefabricated assemblies.

Four: Review mechanical, electrical, fire extinguisher, and security drawings. Record any possible interference with substructure and superstructure erection.

Five: Start identifying work to be done by general contractor and work to be done by subcontractors.

Six: Read and study thoroughly the specifications for the work to be done by the general contractor and those related to any subcontracted work. Also, review general conditions and note the items that will affect project costs.

Seven: Visit the project site and have with you the project manager or field engineer.

Eight: Call a meeting with the personnel who will hold the key supervisory positions. Establish with them the general guidelines for quantities take off and pricing.

Nine: Develop a list of subcontractors. Notify subcontractors and suppliers that the company is preparing a proposal and ask if they intend to submit bids.

Ten: Following the site visit and staff consultation, develop a list of items to be considered for jobsite overhead and general overhead that need to be priced later.

Eleven: Start the quantities takeoff for the category of construction work selected to be done in house (most often site work, foundations, and concrete work). When taking off quantities, break each item down by size, type of material, and workmanship. Also list the type of construction equipment needed for each phase.

Twelve: Condense quantities from the work up sheet by work category and transfer them to a summary sheet for pricing. Pricing means the cost of materials, labor, and construction equipment. The prices used are from company available cost files adjusted to a particular location, or from quotes from suppliers and subcontractors.

4.2 Sources of Cost Information

Not all cost information has the same reputation for accuracy and reliability and care should be exercised when choosing cost data for a new estimate. Cost information required for pricing different work items may be gathered or compiled from different sources.

- Cost information from published price books such as US Means. Price books are published annually and contain a range of prices for standard bills of quantities items.

- Priced bills of quantities from previous projects. A useful source of information as the cost information tends to be current. As with other forms of cost data, there is a need to adjust for differences in location, etc.
- Cost analysis and cost models produced in-house. Depending on the size of an organization, perhaps the most reliable source of cost information, partly due to the fact that it is easier to ensure good quality control on the data. Also data presented in this format will be easily understood and interpreted. A disadvantage is the time and cost taken to prepare and store the information.

4.3 Construction Labor

In today’s fast-paced industrialized age, where many of the products we see are increasingly being mass produced in factories by machines, a building still remains as one of the few handcrafted products put together piece by piece by craftsmen. The construction industry, to which these craftsmen belong, is one of the most labor-intensive industries in the world. The labor cost component of a building project often ranges from 30 to 50%, and can be as high as 60% of the overall project cost. Therefore, it is clear that construction labor is a vital component of a construction project.

A building is a very complex product, made up of many different systems, such as the structural system, exterior enclosure system, and HVAC system. These systems can be broken down into many more subsystems and sub-subsystems. In this way, a building construction project is divided into numerous work packages. These work packages can then be assigned to and completed by an individual worker or a crew. A crew is a team of workers, which can be of the same trade or a composite of many different trades. Due to the diverse nature of the different tasks associated with all the building systems, many types of craftsmen from many different trades are required in a building construction project.

4.3.1 Labor s production rates (Productivity)

A production rate is defined as the number of units of work produced by a person in a specified time. Production rates may also specify the time in man-hours or man-days required to produce a specified number of units of work. The time that a labor will consume in performing a unit of work varies between labors and between projects and with climatic conditions, job supervision, complexities of the operation and other factors. It requires more time for erect shutters for stairs than for foundations.

Sometimes, the production rate is replaced by the term productivity. In the most general sense, productivity is the ratio of input versus the respective output. In construction, the input is often the work hours of a worker or a crew, such as the 8 hours of a bricklayer. The output is the amount of work produced, such as laying 500 bricks. Thus construction productivity is defined as the quantity of work produced in a given amount of time by a worker or a specific crew, that is, the quantity of construction output units produced in a given amount of time or a unit time. The formula for productivity is presented in Eq. 4.1.

Construction productivity = quantity of work produced / time duration (4.1)

Example 4.1

If a bricklayer can lay 500 bricks in 8 hours, then, the associated construction productivity is 500 bricks divided by 8 hours, which is 62 bricks per bricklayer hour.

Although most items associated with the monetary factor remain relatively constant over a short period of time, such as during the construction phase, productivity, on the other hand, can fluctuate wildly. To accurately estimate productivity, an estimator not only needs a good historical record, but a lot of experience.

4.3.2 Productivity sources

Productivity rates can be determined from published sources such as Means' Building Construction Cost Data and Walker's Building Estimator's Reference Book. Figure 4.1 illustrates an excerpt from Means.

09200 Plaster & Gypsum Board

	09210	Gypsum Plaster	CREW	DAILY OUTPUT	LABOR-HOURS	UNIT	2000 BARE COSTS				TOTAL INCL O&P
							MAT.	LABOR	EQUIP.	TOTAL	
100	0010	GYPSUM PLASTER 36 kg bag, less than 0.9 metric ton				Bag	14.20			14.20	15.65
	0100	Over 0.9 metric ton				"	12.90			12.90	14.20
	0300	2 coats, no lath included, on walls	J-1	87.79	0.456	m^2	4.09	11.35	0.62	16.06	22.50
	0400	On ceilings	"	76.92	0.520		4.09	12.95	0.71	17.75	25.00
	0600	2 coats on and incl. 10 mm gypsum lath on steel, on walls	J-2	81.10	0.592		8.20	15.00	0.67	23.87	32.50
	0700	On ceilings	"	69.40	0.692		8.20	17.55	0.79	26.54	37.00
	0900	3 coats, no lath included, on walls	J-1	72.74	0.550		5.70	13.70	0.75	20.15	28.00
	1000	On ceilings	"	65.22	0.613		5.70	15.30	0.83	21.83	30.50

Fig. 4.1: Excerpt form Means' Building Construction Cost Data

For a line item, Means provides the crew types associated with that line as well as two forms of productivity rate: the daily output (unit/day) and labor hours (hr/unit). For example, referring to Figure 4.1, for line 09210-100-0900, the daily output is 72.74 m2 and the labor hours required for one m^2 is 0.550 hours. The bare labor cost for the line item is $13.70/$m^2$. Also, the crew type for this work is Crew J-1. With reference to Figure 4.2, the excerpt from Means' crew listing shows Crew J-1 as consisting of 3 plasterers, 2 plasterer helpers, and 1 mixing machine.

Crew No.	Bare Costs		Incl. Subs O & P		Cost Per Labor-Hour	
Crew J-1	**Hr.**	**Daily**	**Hr.**	**Daily**	**Bare Costs**	**Incl. O&P**
3 Plasterers	$26.65	$639.60	$40.85	$980.40	$24.93	$38.21
2 Plasterer Helpers	22.35	357.60	34.25	548.00		
1 Mixing Machine, 0.17 m^3		54.50		59.95	1.36	1.50
40 L.H., Daily Totals		$1051.70		$1588.35	$26.29	$39.71

Fig. 4.2: Excerpt form Means' Building Construction Cost Data: Crew J-1

The labor hours per unit production are determined by dividing the total labor hours of the crew by the daily output. With reference to line 09210-100-0900 in Fig. 4.1 and Crew J-1 in Fig. 4.2, Figure 4.3 shows the computation involved in determining the weighted wage rate for the crew and bare unit labor cost for the line item.

Crew J-1 consists of 3 plasterer and 2 plasterer helper

$$\text{Weighted Wage Rate (Bare Cost)} = \frac{3(\$26.65) \times 2(\$22.35)}{3+2}$$

$$= \$\ 24.93\ /\text{hr}$$

$$\text{Bare Labor Unit Cost} = \$\ 24.93\ /\text{hr} \times 40\ \text{hr} \div 72.74\ \text{m}^2$$

$$= \$\ 13.70\ /\ \text{m}^2$$

Fig. 4.3: Calculating crew rate

It is important to note the presentation of productivity in labor hours. By keeping the productivity record in labor hours, the record is essentially normalized and is not subjected to the variability in project locations and prevailing wage rates. In this way, unit labor costs for the contractor’s own operating region can be easily developed by multiplying local wage rates including burden and fringe benefits by the productivity rate.

Example 4.2

A contractor determines that the unit productivity for painting a wall is 0.55 hour per m^2. If the local wage rate including burden and fringe benefits is LE30 per hour, the unit labor cost becomes LE16.50 per m^2. If the wage rate is LE20 per hour, the unit labor cost becomes LE11 per m^2. In addition, productivity performance between projects can also be easily compared if contractors keep cost accounting records in man-hours.

4.3.3 Estimating work duration

Determining the total work duration for a task involves knowledge of the quantity of work required for the task and the production rate for the specific crew that will be performing the work. The quantity of work associated with the material quantity is determined by the quantity take off discussed in Chapter 2. A straight forward approach to the estimation of activity durations is to keep historical records of particular activities and rely on the average durations from this experience in making new duration estimates. Since the scope of activities is unlikely to be identical between different projects, unit production rates are typically employed for this purpose. The duration of an activity may be estimated as given in Eq. 4.2.

$$\textit{Work duration} = \textit{quantity of work} \,/\, \textit{number of crews} \times \textit{production rate} \qquad (4.2)$$

Example 4.3

Find the duration of an interior and exterior painting activities with quantities of 440 m^2 and 378 m^2 respectively, using crews of 11 m^2/hours and 14 m^2/hours for the interior and exterior painting activities respectively.

Solution

Interior painting duration = 440 / 11 = 40 hours

Exterior painting duration = 378 / 14 = 27 hours

Total work hours = 67 hours

Typically, the quantity of work is determined from engineering drawings of a specific project. The number of crews working is decided by the planner. In many cases, the number or amount of resources applied to particular activities may be modified in light of the resulting project plan and schedule. Some estimate of the expected work productivity must be provided. Historical records in a firm can also provide data for estimation of productivities.

Having defined a duration of a given work, it means that the planner have already defined the number of resources that will be employed in a particular work. Knowing duration and resources employed, it is simple to estimate the activity direct cost. Then, the three elements of an activity: duration, cost, and resources form what is called construction method. Some activities can be performed using different construction methods. Where, its method will have its own resources, cost and duration.

4.3.4 Basic principle for estimating labor costs

Labor costs in construction are determined by two factors: ***monetary*** and ***productivity***. The monetary factor is related to hourly wage rates, wage premiums, insurance and taxes.

Estimating the components of the monetary factor is more difficult in construction than in other industries. This is due to the variety of work involved in construction, as well as the many types of trades involved. The problem is further complicated by the presence of the unions with their craft structures and collective bargaining processes. Although the computational process of this component seems complex and tedious, it is only a matter of accounting as the needed numbers (such as wage rates, fringe benefits, and insurance) are readily available.

The formula for computing the total cost of labor is quite simple. It requires the knowledge of the total work hours or labor hours needed to perform all the tasks and then applying the corresponding wage rates. The formula for calculating the total cost of labor is shown in Eq. (4.3).

$$\textit{Total cost of labor} = \textit{total work hour} \times \textit{wage rate} \qquad (4.3)$$

Example 4.4

An ironworker works 10hr/day, 6 days/week. A base wage of LE20.97/hr is paid for all straight-time work, 8 hr/day, 5 day/week. An overtime rate of one time and one-half is paid for all hours over 8 hr/day, Saturday through Wednesday, and double time is paid for all Thursday work. The social security tax is 7.65% and the unemployment tax is 3% of actual wages. The rate for worker's compensation insurance is LE12.5 per LE100 of base wage. Calculate the average hourly cost to hire the ironworker.

Solution

Actual hours = 10 × 6 = 60 hr

Pay hours = weekly straight time + weekly overtime + Thursday overtime

= 5 × 8 × 1 + 5 × 2 × 1.5 + 10 × 2 = 75 hr

Taxes are paid on actual wage and insurance is paid on base wage

Average hourly pay	= (75/60) × LE20.97	= LE	26.21/hr
Social security tax	= 26.21 × 0.0765	=	2.01
Unemployment tax	= 26.21 × 0.03	=	0.79
Compensation	= 12.5/100 × 20.97	=	2.62

Then, the average hourly cost = LE 31.63/hr

Example 4.5

Assume that a crew for a work item includes three bricklayers and two helpers. The crew works for three days (8-hr/day) to complete the work package. The wage rate for each bricklayer is LE28.55 and each helper is LE22.40. Find the total cost of the crew.

Solution

In this instance, the total cost of crew is calculated as follows:

Total cost = 3 × 3 × 8 × 28.55 + 2 × 3 × 8 × 22.4 = LE3131

Example 4.6

If the daily production rate for a crew that works in an activity is 175 units/day and the total crew cost per day is LE 1800. The material needed for daily work is 4.5 units at LE 100/unit.

a. Calculate the time and cost it takes the crew to finish 1400 units
b. Calculate the total unit cost. Consider an eight hour work day.

Solution

a. Duration (units of time) = Quantity / Production per unit of time x number of crews
= 1400 / 175 × 1 = 8 days

Cost (labor cost) = Duration (units of time) x crew cost per unit of time
= 8 days × LE 1800 / day = LE 14400

Total direct cost = Le 14400 + 4.5 units of material × LE 100 / day × 8 days
= LE 18000

b. Unit cost = total cost / quantity
= LE 18000 / 1400 = LE 12.86 / unit

Sometimes the productivity of a specific crew expressed in man-hours/unit not units/day. For example, if the productivity is said to be 0.5 Man-hour/cubic meters, this means how long it will take one labor to construct one unit. This way applied to any crew formation and work hours.

Example 4.7

What is the duration in days to install 6000 square feet of walls shuttering if:

a. Crew of 2 carpenters is used with output of 2000 square feet/day
b. Productivity is measured as 0.008 man-hour/square feet. Number of carpenters =3, and number of working hours/day = 8 hours

Solution

a. Duration = 6000 / 200 = 3 days
b. Total man-hours needed = 6000 × 0.008 = 48 man-hours (if one man used)
   Duration = 48 / 8 = 6 days (if one man used)
   Duration using 3 men = 6 / 3 = 2 days

Example 4.8: (use of several resources)

What is the duration of an exaction activity with a quantity of 3000 m^3 using an excavation crew consists of an excavator with a production rate of 200 m^3/day, a loader of 250 m^3/day and 3-trucks of 150 m^3/day? Comment on this crew formation.

Solution

- Using the excavator: Duration = 3000 / 200 = 15 days
- using the loader: duration = 3000 / 250 = 12 days
- using the 3-trucks: duration = 3000 / 150 = 20 days
- then, the activity duration is governed by the lowest production rate = 20 days.

This is unbalanced crew where the loader is not working with full capacity; the production rate of this crew could be adjusted by increasing the number of trucks to 4 of 5 trucks. Then, for a balanced mix of resources, use 1 loader, 1 excavator and 4-trucks. Accordingly, the activity duration = 3000 / 200 = 15 days.

4.4 Construction Equipment

Modern construction is characterized by the increasing utilization of equipment to accomplish numerous construction activities. Equipment refers to all the equipment, tools, and apparatus necessary for the proper construction and acceptable completion of a project. In a construction project, equipment costs are typically divided into portions. The first and bigger portion covers the cost of equipment and is often referred to as equipment cost. It represents the cost of acquiring the equipment and the cost of operating that equipment during the construction processes. The second and smaller portion covers the cost of hand tools. This represents a smaller portion of the project cost and is often calculated as a percentage of payroll costs. It is added to the indirect cost under the jobsite overhead.

4.4.1 Construction equipment classification

Equipment could be classified based on their use as specific use or general use.

4.4.1.1 Specific use equipment

Specific use equipment is for a specific work item or items on the job. Units are assignable to jobs and are not shared by other subcontractors. This equipment is only for specific construction operations and is removed from the job site soon after the task is completed. Its usage is shorter term when compared to general use equipment. The most equipment-intensive operations are: site work, concrete and metal works. Some typical equipment used for site work includes: tractors, scrapers, front shovels, hoes, loaders and backhoe loaders, hauling units, and compactors.

Tractors are self-contained units designed for heavy pushing and pulling work. Tractors can be crawler or wheel type. Crawler or track type units are designed for work requiring high tractive forces, whereas wheel type units sacrifice some of the tractive power while being designed for greater mobility and an ability to travel up to an excess of 50 km/hr. Tractors are one of the most versatile pieces of equipment since they can be modified for different uses by changing the blades and attachments of the units. Typical applications of tractors are land clearing, bulldozing, and ripping earth. In addition, tractors are also often used together with other construction equipment, such as in pushing a scraper during excavation or in pulling a roller compactor during compacting operations.

Scrapers are units designed to load, haul, and dump loose material. Scrapers represent an alternative to using two different pieces of equipment, one for loading and another for hauling. Scrapers are ideal for short hauls of less than a mile and for off-highway work conditions. In addition, the ability to deposit their loads in layers of uniform thickness also facilitates subsequent compaction operations. Front shovels are excavation units used for digging above the surface of the ground on which the piece of equipment rests. A shovel is especially suited for hard digging conditions. On the other hand, hoes, backhoes, or back shovels are excavation units used for digging below the surface of the ground on which the piece of equipment rests. Hoes develop excavation force by pulling the bucket downward and inward towards the unit, and curling the bucket. Apart from pit excavation, hoes are also used for excavating trenches and for the handling and laying of pipes.

Loaders are one of the most common pieces of construction equipment and are used extensively to handle and transport materials, excavate earth, backfill, and as a loading or hauling unit. Backhoe loader units are loaders that have a backhoe attachment on the back of the unit. Hauling units or trucks serve only one purpose, which is to efficiently transport material from one point to another. The longer the distance, the more the justification and advantage is in using trucks rather than other pieces of equipment. This is because trucks are the fastest moving construction unit and they generally cost the least to operate for the moving of material.

Compactors are pieces of equipment used to perform soil compaction. There are many types of compactors available to suit the varieties of soil that can be encountered on a construction site, as well as a required compaction methodology and the desired specified compaction. The above list is not exhaustive and new equipment is continually being developed to handle other specialized tasks in construction.

4.4.1.2 General use equipment

General use equipment has shared utilization by all subcontractors on the construction site and is not associated with any particular work item or items. These pieces of equipment are kept on the site over a longer period of time, throughout almost the entire construction phase. Some examples of general use equipment include: cranes, air compressors, light towers, forklifts and pumps.

Cranes are usually used on building projects. Many types of cranes have been developed to accommodate the variety of construction needs. Cranes can be static, like the tower crane, or they can be movable, as in a wheel- or track-mounted mobile unit. Tower cranes are general use equipment, whereas the mobile type may be specific task equipment. Cranes are used for lifting and moving loads, assisting in the construction installation processes, such as the erecting of precast concrete panels. Air compressors generate pressurized air that is used to power hand tools, such as vibrators and jackhammers. Light towers provide illumination for a work area that lacks sufficient light or when work is carried out beyond daylight. Forklifts are used for the loading and unloading of heavy bulk loads from trucks, the movement of materials to a storage area, and the distribution of the materials to work areas onsite. Pumps are necessary for moving water from a source to a needed area on the site and supply the water pressure needed in some construction activities. Submersible pumps may also be required in the dewatering or draining of water collected in the work area.

4.4.2 Factors influencing equipment selection

Many factors can influence the selection of equipment on a construction site. These factors can be group into three categories: site conditions, the nature of the work, and equipment characteristics.

4.4.2.1 Site conditions

Primary site conditions are: types of material to be handled, onsite physical constraints, and hauling distances. An example that can influence equipment selection is the type of soil encountered. The compaction of clayey soil is done best with a sheep's foot roller, whereas more sandy soil is best compacted with a vibratory roller. Physical constraints onsite refer to site area and layout, surface condition, topography, and adjacent neighborhood. The smaller the site area, the more constraints it has on the mobility of equipment. Smaller equipment may be needed to maintain mobility or bigger units may be required to minimize equipment traffic and site congestion. Selection of cranes is also affected by the shape and layout of the site. Static cranes must have access to all the area around a site to be efficient as they have high mobilization cost. On the other hand, mobile cranes can be more easily relocated but require more workspace and have higher operating costs. The primary surface condition of concern is the bearing capacity of the soil. Low bearing capacity soil may dictate the selection of track-type instead of wheel-type equipment. The neighborhood of the construction site must be considered, such as other buildings and traffic in the area, as it can also offer obstacles to equipment movement or certain construction operations.

Hauling distances can affect the selection of equipment. For short hauls, a loader can pick up the load and move it to a dump area by itself. However, for longer hauling distances, the loader can be just used loading and a dump truck can be used for hauling and dumping. The longer the hauling distance, the more advantage is in using higher capacity hauling units since they can be more cost effective.

4.4.2.2 The nature of the work

Some factors relating to the nature of the work include payload, the total quantity of work, and the construction schedule. Payload has a direct relation to the capacity of the equipment selected. For example, the particular crane selected must be able to lift the maximum load the work may require. A higher quantity of work can influence and justify the selection of higher capacity equipment. Although higher capacity equipment has higher mobilization and rental costs, the per-unit production costs are lower. Therefore, given a higher quantity of work, the savings in unit production costs could be high enough to offset higher mobilization and rental costs, and thus result in lower total costs.
On some projects, costs may not be the governing constraint; instead, the construction

schedule might be. A tighter schedule often requires higher productivity units, such as those with higher power, bigger capacity, more mobility, and faster deployment.

4.4.2.3 Equipment characteristics

Equipment characteristics are related to equipment capabilities (capacities and versatility) and costs. Capacity can be in the form of maximum allowable payload and maximum volume that can be handled. It can also relate to the power, mobility, or maneuverability of a piece of equipment. Versatility refers to the degree of applicability of a unit to perform many different operations. For example, a dozer can be adapted to perform many tasks by simply changing a blade or adding additional attachments. Versatility can make a piece of equipment more useful on a site, thus replacing the need for more specialized units. Cost is certainly an important consideration in equipment selection.

All the above factors can be related and they all must be considered together in equipment selection. Equipment planning can yield many solutions. Many decisions involve trade-offs that must be properly analyzed to identify the best solution. For example, choosing two smaller pieces of equipment instead of one larger unit may mean higher unit production costs, but there is a redundancy in the system that can be good insurance if one unit should break down and work can be kept moving. Considering the above factors that can influence equipment selection, the outcome of equipment planning should yield a solution that satisfies the following three underlying objectives in equipment selection: feasibility, efficiency, and economy.

The feasibility refers to the selection of equipment that can carry out the tasks in a satisfactory manner. This is determined by the nature of the work that the equipment will perform and the condition in which the equipment will do the work. Efficiency refers to the selection methods that maximize efficiency of the construction operation such as those decisions that can reduce the number of equipment pieces through selecting higher capacity units. Efficiency in operation may not have a direct effect on the direct cost of the project but may have an indirect effect on other aspects of the construction project, such as minimizing site congestion leading to higher productivity, while decreasing the likelihood of accidents and promoting communication and coordination. Finally, the selected pieces of equipment and methods that produce the lowest cost are ideal for the project as they directly contribute to lower construction costs, which is one of the goals of every construction project.

4.4.3 Renting versus purchasing equipment

The purchase of equipment represents a capital investment by the construction contractor. The contractor must recover sufficient money to pay the ownership and operating costs of the equipment during its useful life, and at the same time make a profit on the investment. Any estimate must include the cost of equipment used on the project. Construction equipment could be purchased or rented. The choice between purchase and rental usually depends on the amount of time the equipment will be used in the contractor's operations. If extensive use of the equipment is required, the equipment is always purchased. If the equipment is to be used a limited amount of time, it is typically rented.

A contractor does not necessarily have to own any construction equipment in order to carry on business. There can be distinct advantages to renting equipment, including:

- No need to maintain a large inventory of specialized equipment.
- Continuous access to the newest and most efficient items of available equipment.
- No need for equipment warehouse and storage facilities.
- Reduced need to employ maintenance staff and operate facilities for their use.
- Equipment cost accounting is simpler when equipment is rented.

Contractors may purchase equipment when factors pertaining to ownership and economics make this alternative more favorable than renting. When the construction operations of a contractor need the steady use for certain equipment, owing such equipment may be financially better. There can be, also, a marketing advantage to the contractors who own their equipment which shows that they are more financially stable than others who do not own their equipment. Some owners ask contractors who bid on their projects to list on the bid the company-owned equipment they propose to use in the work. This information is used in the owner's assessment of the bidder. Also, the advantage of purchasing equipment is that it allows a contractor to have absolute control on the use and disposition of equipment. He/she can use the equipment in any manner fits the required job. Decisions on maintenance and servicing can be easily made, thus ensuring the desired operational performance.

4.4.4 Time-value of money

The value of money is dependent on the time at which it is received. A sum of money on hand today is worth more than the same sum of money to be received in the future because the money on hand today can be invested to earn interest to gain more than the same money in the future. Thus, studying the present value of money (or the discounted value) that will be received in the future is very important. This concept will be demonstrated in the following subsections.

4.4.4.1 Single payment

The Future Value of a given present value of money represents the amount, at some time in the future, that an investment made today will grow to if it is invested to earn a specific interest rate. For example, if you were to deposit LE100 today in a bank account to earn an interest rate of 10% compounded annually, this investment will grow to LE110 in one year. The investment earned LE10. At the end of year two, the current balance LE110 will be invested and this investment will grow to LE121 [110 x (1 + 0.1)]. Accordingly, investing a current amount of money, *P*, for one year, with interest rate (*i*) will result in a future amount, *F* using the following equation.

$$F = P \times (1 + i) \tag{4.4}$$

If *P* is invested for *n* years then the future amount *F* will equals:

$$F = P \times (1 + i)^n \tag{4.5}$$

In contrary to the Equation 4.4, the present value (the discounted value), *P*, of a future some of money, *F*, that will be received after *n* years if the discount rate is "*i*" is calculated as follow:

$$P = F / (1 + i)^n \tag{4.6}$$

For example, the present value of LE100 to be received three years from now is LE75.13

if the discount rate is 10% compounded annually.

4.4.4.2 Uniform series of payment

The Future Value, *F*, of a uniform annual payment, *C*, is calculated at the end of the period, *n*, in which the last payment occurs with an investment rate *i*. Thus, the future value of a five year annual payment is computed at the end of year five. The Future Value of the uniform annual payments is equal to the sum of the future values of the individual payments at that time. This can be found in one step through the use of the following equation:

$$F = C\left[\frac{(1+i)^n - 1}{i}\right] \qquad (4.7)$$

The term within the brackets of Eq. 4.7 is called the ***uniform series compound factor***. Consider the annual payment of LE100 per year for five years given. If the discount rate is equal to 10%, then the Future Value of this annual payment at the end of period five can be found as follows:

F = 100 [((1+0.1)5-1)/0.1] = LE610.51

Accordingly, the annual uniform amount, *C*, to be invested at the end of each period in order to produce a fixed amount, *F*, at the end of *n* periods with interest rate *i* could be calculated as follow from Eq. 4.7.

$$C = F\left[\frac{i}{(1+i)^n - 1}\right] \qquad (4.8)$$

Equation 4.8 could be used to convert a future amount of money, *F*, will be received after *n* years into equal annual payments, *C*. The term between the brackets in Eq. 4.8 is called the ***sinking fund factor***.

Now, the present value, *P*, of a future amount of money, *F*, from a uniform series payments, *C*, could be calculated from Eq. 4.7 as follow:

$$P = C\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \tag{4.9}$$

Equation 4.9 is called the uniform series present worth formula and the term in brackets is called the ***uniform series present worth factor***. Using the uniform series present worth formula (Eq. 4.9), the value of a uniform series payment, C, when the present sum, P, is known could be determined as follow:

$$C = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \tag{4.10}$$

The value between the brackets in Eq. 4.10 is called ***uniform series capital recovery factor***.

Example 4.9

On January 1, a man deposits LE5000 in a bank that pays 8% interest, compounded annually. He wishes to withdraw all the money in five equal end-of-year sums beginning December 31st of the first year. How much should he withdraw each year?

Solution

P = 5000; n = 5; i = 8%; C = unknown

$C = 5000[(0.08 \times 1.08^5) / (1.08^5 - 1)]$ = LE1252

Example 4.10

A man deposits LE500 in a bank at the end of each year for five years. The bank pays 5% interest, compounded annually. At the end of five years, immediately following his fifth deposit, how much will he have in his account?

Solution

C = 500; n = 5; i = 5%; F = unknown

$F = 500[(1.08^5 - 1) / 0.05]$ = LE2763

4.4.5 Equipment costs

The cost per unit of time of owning an item of equipment has to be determined. Costs associated with owing equipment called the ownership costs. Estimating equipment cost involves identifying the ownership and operating costs. Ownership costs include: initial cost, financing (investment) costs, depreciation costs and taxes and insurance costs. The operating costs include: maintenance and repair costs, storage costs and fuel and lubrication costs.

4.4.5.1 Initial cost

The initial cost is the total cost required to purchase a piece of equipment. This initial cost is the basis for determining other costs related to ownership as well as operating costs. Generally, initial cost is made up of: price at the factory or used equipment price, extra options and accessories, sales tax, freight and assembly or setup charges. The initial cost is very straight forward, whereas the other costs require more analysis and computation.

4.4.5.2 Investment cost

The purchase of construction equipment requires a significant investment of money. This money either be borrowed from a lender, or it will be taken from reserve fund of the contractor. Either the lender will charge an interest rate for the borrowed money, or the contractor will lose any interest money that could be gained if the contractor invest that amount of money used to purchase a piece of equipment.

In order to calculate the cost of finance (or investment cost) of an equipment, both the purchase price, P, and the salvage value, F, should be converted into uniform annual values using Eqs. 4.10 and 4.8 respectively. In this situation, the purchase price is considered as a present value invested for n yeas as a series of uniform payments (equipment useful life) and the salvage value is considered as a future sum of money to be discounted for n years as a series of uniform payments.

$$Annual\ cost\ of\ finance = \left[P\left(\frac{i(1+i)^n}{(1+i)^n-1}\right)-\frac{P}{n}\right]-\left[F\left(\frac{i}{(1+i)^n-1}\right)-\frac{F}{n}\right] \quad (4.11)$$

Example 4.11

An excavator purchase price is LE460,000 and its salvage value is LE40,000 after 10 years of useful life. Find the annual cost of finance of this excavator if the annual interest rate is 15%.

Solution

P = 460,000; F = 40,000; n = 10; i = 15%

$$Annual\ cost\ of\ finance = \left[460000\left(\frac{0.15(1.15)^{10}}{(1.15)^{10}-1}\right)-\frac{460000}{10}\right]-\left[40000\left(\frac{0.15}{(1.15)^{10}-1}\right)-\frac{40000}{10}\right]$$

Annual cost of finance = LE47,684/year

4.4.5.3 Depreciation

The depreciation in defined as “the decrease in market value of an asset”. A machine may depreciate (decline in value) because it is wearing out and no longer performing its function as well as when it was new. Many kinds of machinery require increased maintenance as they age, reflecting a slow but continuing failure of individual parts. Also, the quality of outputs may decline due to wear in components. Another aspect of depreciation is that caused by obsolescence. A machine is described as obsolete when the function it performs can be done in some better manner. A machine may be in excellent working condition, yet may still be obsolete. For example, electronic machines, computers, etc.

As asset always has different values: initial value, book value, salvage value and market value. The initial value represents the purchase price of an asset. Salvage value represents the expected price for selling the asset at the end of its useful life. The book value represents the current value in the accounting systems. The book value equals the initial value of the asset minus all the depreciation costs till given time. The book value is always calculated at the end of each year. The market value, on the other hand, represents the value of the asset if it is sold in the free market. It is not necessary that the book value equals the market value.

Depreciation is an accounting charge that allows for the recuperation of capital that was used to procure equipment or other physical assets. There are three common methods for calculating depreciation expense for financial accounting purposes: straight-line, sum-of-years digits and the sinking fund method. Each method involves the spreading of the amount to be depreciated over the recovery life of an asset in a systematic manner.

Each depreciation method selected produces different patterns of depreciation expense per period. The straight-line method assumes linear depreciation or the depreciation cost is allocated equally over the asset useful life. The sum-of-years digits assumes high rate of depreciation at the early age of an asset and decreasing rate at its aged life. The Third method assumes lower rate at the early ages and faster rate at the late age.

<u>Straight-Line method</u>

The simplest and best known of the various depreciation methods is the straight-line depreciation method. In this method a constant depreciation charge is made. To obtain the annual depreciation charge at any year, D_n, the total amount to be depreciated (initial value, P – salvage value, F) is divided by the useful life in years, N.

$$\text{(Annual depreciation charge) } D_n = (P - F) / N \qquad (4.12)$$

Example 4.12

If the purchase price of an equipment is LE60,000 and its salvage value after 8 years is LE6,000, calculate the annual depreciation and the book value of the equipment each year.

Solution

P = 60,000; F = 6,000; N = 8;

Total depreciation = 60000 – 6000 = LE54,000

Annual depreciation = 54000 / 8 = LE6,750

Notice that the book value of the equipment equals its salvage value at the end of its useful life as shown in Table 4.1.

Table 4.1: Straight-line depreciation of Example 4.12

Year	Annual depreciation	Book value
0	0	60,000
1	6,750	53,250
2	6,750	46,500
3	6,750	39,750
4	6,750	33,000
5	6,750	26,250
6	6,750	19,500
7	6,750	12,750
8	6,750	6,000

Sum-of-years digits method

Another method for allocating the cost of an asset minus its salvage value over its useful life is called sum-of-years digits depreciation method. This method results in faster depreciation at the early life of an asset. Larger depreciation charges than straight-line depreciation during the early years of an asset and smaller charges as the asset nears the end of its estimated life. Each year, the depreciation charge is computed as the remaining useful life at the beginning of the year divided by the sum of the years digits for the total useful life, with this ratio multiplied by the total amount of depreciation (P – F). Thus means that the depreciation is calculated as the percentage of the remaining life to the original life.

For an asset with useful life N, to obtain the annual depreciation charge, D_n, at any year n, can be calculated as follows:

D_n = (Remaining useful life at beginning of a year / Sum of years digits) × (P – F)

$$D_n = \left[\frac{N - n + 1}{N(N+1)/2} \right] \times (p - F) \qquad (4.13)$$

Example 4.13

Resolve Example 4.12 using the straight-line depreciation method.

Solution

P = 60,000; F = 6,000; N = 8

Sum-of-years digits = 8 (8 + 1) / 2 = 36 years

The calculations are shown in the following table (Table 4.2).

Table 4.2: Sum-of-years depreciation of Example 4.13

Year	Remaining life / sum-of-years	Annual depreciation	Book value
0	0	0	60,000
1	8/36	12,000	48,000
2	7/36	10,500	37,500
3	6/36	9,000	28,500
4	5/36	7,500	21,000
5	4/36	6,000	15,000
6	3/36	4,500	10,500
7	2/36	3,000	7,500
8	1/36	1,500	6,000

<u>Sinking fund method</u>

This method assumes that a uniform series of end-of-payments are deposited into an imaginary sinking fund at a given interest rate i. The amount of the annual deposit is calculated so that the accumulated sum at the end of the asset life, and at the stated interest rate, will just equal the value of the asset depreciated (i.e., $P - F$). The amount of yearly depreciation is invested in a compound manner for the remaining period as a uniform series of payments using Eq. 4.10 as follows:

$$C = (P - F) \times \left[\frac{i}{(1+i)^n - 1} \right] \qquad (4.14)$$

Then the depreciation value, D_n, at any year n is calculates using the following equation.

$$D_n = C \times (1 + i)^{n-1} \qquad ; n = 1, 2, 3, \ldots\ldots\ \ldots\ldots, N \qquad (4.15)$$

Example 4.14

Resolve Example 4.12 using the sinking fund depreciation method, assuming that the interest rate is 10%.

Solution

P = 60,000; F = 6,000; N = 8; i =10%

C = (60000 – 6000) × [(0.1) / (1.1^8 – 1)] = LE4,722

Accordingly, the annual depreciation could be calculated as follows:

At the first year: D_1 = LE4,722

At the second year: D_2 = 4722 × (1.1) = LE5,194

At the third year: D_3 = 4722 × (1.1)^2 = LE5,714

……………..

At the eighth year: D_8 = 4722 × (1.1)^7 = LE9,202

The results of the depreciation calculations are summarized in Table 4.3.

After studying depreciation calculations from the previous listed three methods, Figure 4.3 illustrates the difference between the three methods. The figure shows that the sum-of-year digits method gives an accelerated depreciation compared to the straight-line method. On the other hand, the sinking fund is a decelerated method compared with the straight-line method. However, the straight-line method is the commonly used for calculating asset depreciation.

Table 4.3: Sinking fund depreciation of Example 4.14

Year	Annual depreciation	Book value
0	0	60,000
1	4,722	55,278
2	5,194	50,084
3	5,714	44,370
4	6,285	38,085
5	6,913	31,172
6	7,605	23,567
7	8,365	15,202
8	9,202	6,000

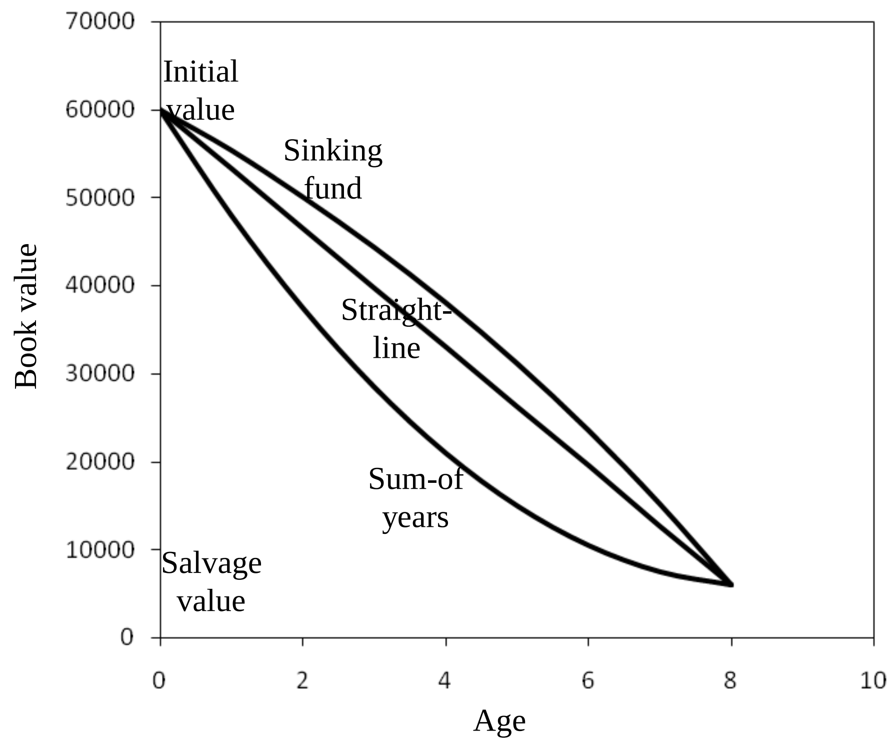

Figure 4.3: Comparison among the three depreciation methods

4.4.5.4 Operating costs

Operating cost accrue only when the unit of equipment is used, whereas ownership costs accrue whether or not the equipment is used. Operating costs include maintenance and repairs, fuel, oil and lubricants. The amounts consumed by a piece of equipment vary with the type and size of equipment, the conditions under which it is operated. An equipment is seldom used its total horse power and also it is seldom to work for 60 minute/hour. Thus, the fuel consumed should be based on the actual operating conditions. Perhaps the average demand on an engine might be 50 percent of its maximum power for an average 45 minutes/hour.

Maintenance and repair costs

The cost for maintenance and repairs include the expenditures for replacement parts and the labor required to keep the equipment in good working condition. Historical cost records of maintaining and servicing equipment are the most reliable guide in estimating maintenance and repair cost. The manufacturers of construction equipment provide information showing recommended costs for maintenance and repairs for the equipment they manufacture. The annual cost of maintenance and repairs is often expressed as a percentage of purchase prices or as a percentage of the straight-line depreciation costs.

Fuel consumption

When operating under standard conditions, a gasoline engine will consume approximately 0.06 gallon of fuel for each horsepower-hour developed. A diesel engine will consume approximately 0.04 gallon of fuel for each horsepower-hour developed.

Lubricating oil consumption

The quantity of lubricating oil consumed by an engine varies with the size of the engine, the capacity, the equipment condition and the number of hours between oil changes.

Cost of rubber tires

Many types of construction equipment use rubber tires, whose life usually will not be the same as the equipment on which they are used. For example, a unit of equipment may have an expected useful life of six years, but the tires on the equipment may last only for two years. Therefore, a new set of tires must be placed on the equipment every two years, which would require three sets of tires during the six years the equipment will be used. Thus, the cost of depreciation and repairs for tires should be estimated separately from the equipment.

Example 4.15

Calculate the ownership cost per hour for an excavator powered by a 250-hp engine based on the following data:

- Purchase price (P) = LE420,000
- Salvage value (F) = LE250,000
- Operation factor = 50%
- Useful life (N) = 6 years
- Working hours per year = 2000
- Maintenance and repair costs = 110% of annual depreciation
- Diesel fuel price = 3.8/gallon
- Fuel consumption = 0.04 gallon/hp/hr
- Lube oil cost = 10% of fuel
- Interest rate (i) = 10%

Solution

Depreciation (assume straight-line) = (420000 – 250000) / 6 = LE28333.33/year

Investment annual cost is calculated as follows:

$$Annual\ \ investment = \left[420000\left(\frac{0.1\,(1.1)^6}{(1.1)^6-1}\right)-\frac{420000}{6}\right]-\left[250000\left(\frac{0.1}{(1.1)^6-1}\right)-\frac{250000}{6}\right]$$

Annual investment = (420000 × 0.2296 – 70000) – (250000 × 0.1296 – 41666.67)

= 26432 – (- 9264.82) = LE35696.82/year

Maintenance and repair cost = 1.1 × 28333.33 = LE31166.67/year

Then, the total yearly costs = 28333.33 + 35696.82 + 31166.67 = LE95196.81/year

Accordingly, the hourly cost = 95196.81 / 2000 = LE47.6/hr

Fuel consumption = 250 × 0.04 × 0.5 = 5 gallon/hr

Fuel cost = 5 × 3.8 = LE19/hr

Lubricate oil cost = 19 × 0.1 = LE1.9/hr

Finally, the total hourly cost = 47.6 + 19 + 1.9 = LE68.5/hr

Example 4.16

Calculate the hourly arte of equipment based on the following data:

- Purchase price (*P*) = LE460,000
- Salvage value (*F*) = LE40,000
- Useful life (*N*) = 10 years
- Working hours per year = 2000 years
- Annual maintenance costs = 10% of purchase price
- Annual operating costs = LE47,000
- Interest rate (*i*) = 15%

Solution

Depreciation (assume straight-line) = (460000 – 40000) / 10 = LE42000/year

Investment annual cost is calculated as follows:

$$Annual\ \ investment = \left[460000\left(\frac{0.15(1.15)^{10}}{(1.15)^{10}-1}\right)-\frac{460000}{10}\right]-\left[40000\left(\frac{0.15}{(1.15)^{10}-1}\right)-\frac{40000}{10}\right]$$

Annual investment = LE47684/year

Maintenance and repair cost = 0.1 × 460000 = LE46000/year

Operating costs = LE47000/year

Then, the total annual costs = 42000 + 47684 + 46000 + 47000 = LE182684/year

Accordingly, the hourly cost = 182684/ 2000 = LE91.34/hr

4.5 Exercises

1. The construction of RC wall involves placing 660 m^3 concrete, 50 t of steel, and 790 m^2 of formwork. Calculate the duration of the activity using a balanced mix of the resources if:
   - A 6 man concrete gang can place 16 m^3 of concrete / day.
   - One steelfixer and one assistant can fix 0.5 t of steel / day.
   - One carpenter and one assistant can fix and strike 16 m^2 / day.

2. Estimate the labor cost for the formwork of a continuous wall footing that has a quantity of 500 SF. The activity is constructed by crew that has a daily output of 485 SF/day, and consists of: 3 carpenters at rate LE 21.60/hr & 1 building labor at rate LE 17.15/hr.

3. A crew of four carpenters and two labors is used to build the formwork for a concrete structure. Work is scheduled for 9 hr/day on Saturday through Wednesday and 8 hr on Thursday. Overtime at a rate of one and one-half will be paid for all hours over 8 hr/day during the week and double time for all Thursday work. The base wage, taxes and insurance rates are given in the table below. Calculate the hourly and weekly cost of the crew.

Item	Carpenters	Labors	Notes
Base wage	LE21/hr	LE15/hr	
Worker's compensation	LE19/LE100	LE16/LE100	of base wage
Social security	7.%	7%	of actual wage
Unemployment insurance	3%	3%	of actual wage
Benefits	LE3.5/hr	LE2.5/hr	

4. A small concreting subcontractor keeps track of his resources (L1, L2, E1, E2, C1, M1) and also keeps information related to his frequently used concreting methods (Md1, Md2). The subcontractor is currently preparing an estimate for a

new concreting job in which he has to pour 600 m3 of concrete. A normal working day is eight hours.

- The rate for labor overtime per hour is considered to be 1.5 normal rates. The crew production during an overtime hour is 90% of their production in a regular hour.
- If the subcontractor is free to use either of the two methods of construction, Md1 and Md2. It is required to calculate the total cost and time required to finish the job in both cases taking into consideration the following information:
  - Labor L1 rate is 20 LE/hr & labor L2 rate is 30 LE/hr.
  - Equipment E1 cost (rental and operational) is 80 LE/hr & Equipment E2 (rental and operational) cost is 160 LE/hr.
  - The material M1 (ready mix concrete) unit cost is 250 LE/m^3.
  - Crew C1 formation is (2 L1 + 3 L2 + 1 E1 + 1 E2).
  - Required resources for Md1 (Concreting by pump – 8 hrs/day) are C1+M1 and its production rate is 100 m^3/day (Normal hours).
  - Required resources for Md2 (Concreting by pump – 14 hrs/day) are C1+M1 (6 Over time hrs/day).

5. An investor holds a time payment purchase contract on some machine tools. The contract calls for the payment of LE140 at the end of each month for a five years period. The first payment is due in one month. He offers to sell you the contract for LE6,800 cash today. If you otherwise can make 1% per month on your money, would you accept or reject the investor's offer.

6. A company purchased a piece of equipment 3 years ago with an initial value of LE15,000, salvage value of LE3,000, annual operating cost of LE2,000, and estimated life of 10 years. Calculate the book value of the machine now using the straight-line, sum-of years digits and sinking fund depreciation method. Assume interest rate 10%.

7. Calculate the ownership cost per hour for a dump truck powered by a 120-hp gasoline engine based on the following data:

-	Purchase price	= LE175,000
-	Freight charges	= LE2,000
-	Estimated salvage value	= LE57,500
-	Operation factor	= 40%
-	Useful life	= 5 years
-	Hours used per year	= 1800
-	Maintenance and repair	= 130% of annual depreciation
-	Tire cost	= LE5,000
-	Tire life	= 4,000 hours
-	Maintenance and repairs (tires)	= 15% of tire depreciation
-	Gasoline fuel price	=LE4.0/gallon
-	Fuel consumption	= 0.06 gallon/hp/hr
-	Lube oil cost	= 10% of fuel
-	Interest rate (*i*)	= 10%

8. A backhoe will be purchased for a cost of LE109,750. After a useful life of 5 years, it is assumed the equipment will be sold for LE35,000. Assume interest of 8% for borrowing money, 4% for risk and 2% for taxes, insurance and storage. Calculate the annual ownership cost and the cost per hour assuming the equipment will be used 1800 hr/year.