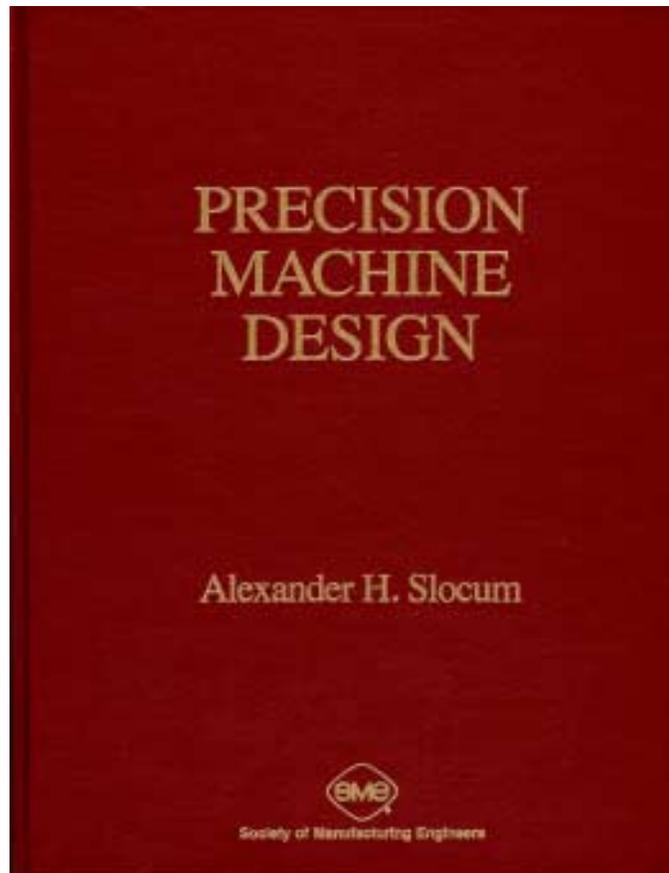


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Society of  
Manufacturing  
Engineers

# Chapter 1

## Introduction to Precision Machine Design

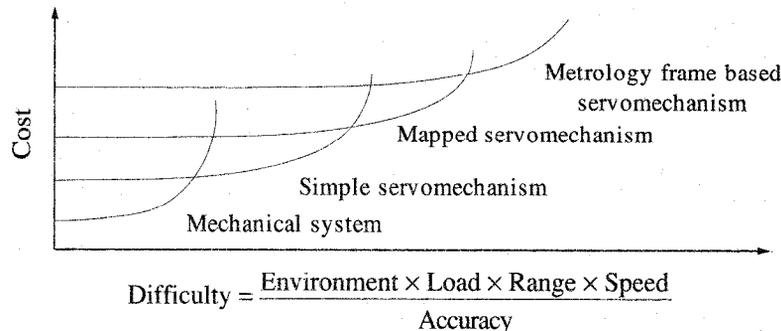
*Why do you like to design machines? "It is the pitting of one's brain against bits of iron, metals, and crystals and making them do what you want them to do. When you are successful that is all the reward you want."*

Albert A. Michelson

### 1.1 INTRODUCTION

Companies can remain competitive in world markets only if they develop new technologies and methods to keep one step ahead of the competition; maintaining the status quo is not acceptable. Hence new machines need to be designed with increased speed, accuracy, and reliability. This leads to the need for designers who have a deep understanding and love of the art and science of design.<sup>1</sup>

In a broad sense, the art and science of design is a potent vitamin that must be taken in balance with other mental nutrients, such as mathematics, physics, manufacturing, hands-on experience, and business skills. Most people exercise to keep physically fit so they can enhance their enjoyment of day-to-day living. Analogous to physical exercise, analysis is a form of mental pushup that trains the mind to be strong and swift. Indeed, many designs would never have even been conceived of if the design engineer did not understand the basic physics behind the process that prompted the need for a new design. Similarly, knowing how to build things can enable the design engineer to develop easily manufacturable products that are a pleasure to use. As illustrated in Figure 1.1.1, the need to integrate various disciplines means today's design engineer must be a Renaissance person. Design engineers must be more creative than their competition and more observant of the world around them. In today's tough international competitive world, if you want something, you can only obtain it with blood, sweat, tears, and design.



**Figure 1.1.1** Increasing difficulty often leads to the integration of engineering disciplines.

In the future, expert systems may evolve to replace mundane engineering tasks. However, it is unlikely that computers will ever be able to do creative design. If a computer program can be designed to do creative design, a computer program can also be designed to design new computer programs. Thus there will always be jobs for creative design engineers. However, high-paying engineering jobs will soon no longer be available for students who lack good creative and/or analytic skills.<sup>2</sup> On the other hand, the future for bright, creative, hard-working design engineers is very promising. How can new design engineers be taught to think and be creative? Integrating theory and application with real-world considerations seems to be a good method and is stressed in following chapters. The remainder of this chapter addresses broad issues including:

- Basic economics
- Design philosophies
- Basic project management skills
- The design process in the real world

<sup>1</sup> "Enthusiasm is one of the most powerful engines of success. When you do a thing, do it with all your might. Put your whole soul into it. Stamp it with your own personality. Be active, be energetic, be enthusiastic and faithful and you will accomplish your object. Nothing great was ever achieved without enthusiasm." Ralph Waldo Emerson

<sup>2</sup> "The hero of my tale, whom I love with all the power of my soul, whom I have tried to portray in all his beauty, who has been, is, and will be beautiful, is Truth." Leo Tolstoy

## 1.2 FUNDAMENTALS OF ECONOMIC ANALYSIS<sup>3</sup>

The initial specifications for a machine are often generated by a company's salespeople, who are responding to requests from customers; however, it often seems as if the customer wants infinite performance for zero cost. When presented with customer requirements, it is the duty of the design engineer to sketch out realistic options and cost estimates for a family of possible designs that could meet the customer's specifications. This initial step is usually done by senior design and manufacturing engineers with experience in determining just how long and how much it will cost to design and build a new product.

The underlying principle of economic analysis is that money has different values depending upon when it is actually received or spent. The simplest example of this is a traditional passbook savings account; \$1000 deposited today at 6% interest will be worth approximately \$1349 five years from now. The amount of \$1000 today or \$1349 in 5 years is equivalent, assuming that 6% is the highest interest rate you could obtain. Because money received or paid out at some future time has a different value when considered at "what it is worth today," economic analysis is vital to decisions on machinery purchases and hence can greatly influence a machine's design. It should be stressed that there are many ways to evaluate an investment decision; the necessary brevity of this section precludes a more detailed discussion, and it is recommended that all engineers complete an engineering economics course at some point in their career.

### 1.2.1 Cashflow Timelines

The first step in evaluating an investment is to identify the applicable cashflows, as well as when they are expected to occur. One convenient method for visualizing cashflows is to mark them on a timeline.

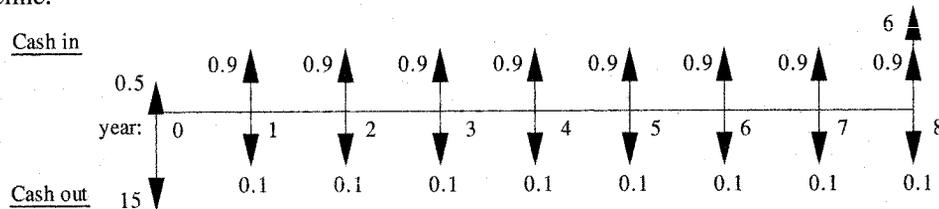


Figure 1.2.1 Cashflow (thousands of dollars) timeline for Example 1.

#### Example 1

An automated drill press is under consideration for purchase for \$15,000. It is estimated that by replacing the old drill press with a new one, the company will save \$900 per year in labor costs, but there will be an added maintenance cost of about \$100 per year. The old press can be sold for \$500 today, and the estimated salvage value of the new press in 8 years is \$6000. Figure 1.2.1 shows the applicable cashflows as a function of time. Subtracting the "cash out" amounts from the "cash in" amounts for each given year, the result is the net cashflow timeline shown in Figure 1.2.2. The timeline demonstrates that in the beginning of the first year ( $t = 0$ ), the company has a net negative cashflow of \$14,500. In years 1 to 7 there is a net positive cashflow of \$800, and in year 8 there is a \$6800 positive cashflow from the sale of the machine and that year's profits. To answer the question "Should the company buy the new drill press?", it is necessary to evaluate the predicted cashflows; doing so requires an understanding of compound interest factors.

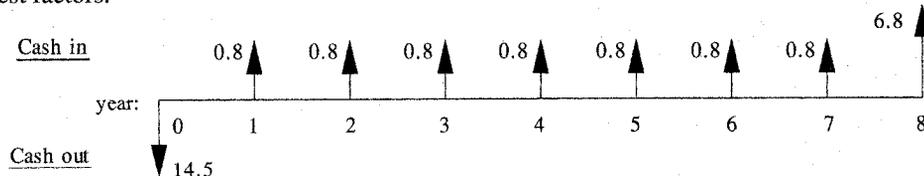


Figure 1.2.2 Net cashflow (thousands of dollars) timeline for Example 1.

<sup>3</sup> Section 1.2 was written by Richard W. Slocum III.

### 1.2.2 Compound Interest Factors

The *time value of money* concept is also referred to as *interest* and *interest compounding*. The value of various types of cashflows at different times along the timeline can be calculated, using the following mathematical factors/formulas, in which  $i$  is the interest rate per period (e.g.,  $i = 0.1$  for 10% interest) and  $n$  is the number of periods.

- *Single-Payment Future Worth Factor*: This gives the value of a cashflow now ( $t = 0$ ) at some time  $n$  periods in the future:

$$(F/P, i, n) = (1 + i)^n \quad (1.2.1)$$

- *Single-Payment Present Worth Factor*: This gives the present value ( $t = 0$ ) of a cashflow that will occur  $n$  periods in the future:

$$(P/F, i, n) = \frac{1}{(1 + i)^n} \quad (1.2.2)$$

- *Uniform Series Future Worth Factor*: This gives the value (at some time  $n$  periods in the future) of a uniform series of cashflows occurring once per period:

$$(F/A, i, n) = \frac{(1 + i)^n - 1}{i} \quad (1.2.3)$$

- *Uniform Series Present Worth Factor*: This gives the present value ( $t = 0$ ) of a uniform series of cashflows occurring once per period:

$$(P/A, i, n) = \frac{(1 + i)^n - 1}{i(1 + i)^n} \quad (1.2.4)$$

- *Capital Recovery Factor*: This gives the uniform series of cashflows over  $n$  future periods that are equivalent to one cashflow at the present ( $t = 0$ ):

$$(A/P, i, n) = \frac{i(1 + i)^n}{(1 + i)^n - 1} \quad (1.2.5)$$

The product of the principal and the CRF is the payment due each period. This is the factor used to calculate the payment required to repay a car loan or a home mortgage.

- *Sinking Fund Factor*: This gives the uniform series of cashflows over  $n$  future periods that are equivalent to one large cashflow in period  $n$ :

$$(A/F, i, n) = \frac{i}{(1 + i)^n - 1} \quad (1.2.6)$$

It used to be that these formulas were too cumbersome to use, so they were tabulated for various interest rates and time periods; however, modern programmable and financial calculators and PC-based spreadsheet programs eliminate this problem.

#### Example 2

Fred wishes to borrow \$12,000 to apply toward purchase of a new car. If the bank is offering 5-year loans at 12%, what will Fred's monthly payment be? The *Capital Recovery Factor* is used here. The period is 1 month, there are 60 periods in 5 years, and the interest rate per period is 12%/12 months per year, or 1%: Monthly car payment =  $(A/P, 1\%, 60) \times \$12,000$ . The  $A/P$  factor is 0.02224, so Fred's payment is \$266.88 per month.

**Example 3**

Mary is presently a sophomore in college and she wishes to begin a monthly savings program that will accumulate enough money so that by graduation she will be able to make a down payment on a home. She has 29 months until graduation and estimates that \$11,000 will be required for a down payment. If interest rates on deposits remain constant at about 6%, how much should she save each month? The *Sinking Fund Factor* is used here. There are 29 periods and the interest rate per period is 6%/12 months per year, or 0.5%/period: Required monthly savings =  $(A/F, 0.5\%, 29) \times \$11,000$ . The A/F factor is 0.0321, so Mary must save \$353.10 per month.

**1.2.3 Economic Analysis of Projects**

Economic evaluation of projects involves a determination of whether a series of cashflows over time, as shown in the timeline of Example 1, meet a company's investment criteria. Usually, a company's management establishes a minimum interest rate that investments must provide in order to be considered worthwhile.<sup>4</sup> It is generally safe to say that this minimum rate is somewhere near the rate for long-term government Treasury bonds (which are virtually risk-free), plus a factor for estimated risk. For example, if Treasury bonds yield a risk-free 9%, why should the company invest in a high-risk project unless that project will yield at least the T-bill rate plus, say, 3% to cover the increased risk? In this instance, management would thus set the minimum interest rate at 12%. The minimum interest rate is referred to by a number of terms including:

- Desired (minimum) rate of return
- Hurdle rate
- Discount rate
- Desired (minimum) yield

All refer to the same interest  $i$  as discussed above.

There are two principal methods for determining if a series of cashflows meet an established minimum rate of return:

1. Calculate the rate of return that results from the cashflows, and compare it to the minimum rate of return. Calculation of rate of return is a matter of setting up the applicable cash flows with the appropriate factors (P/A, A/F, and so on), and then solving for the interest  $i$  in the expression for the sum total of all cashflows (in and out):  $PW_i = 0 = \text{sum of cash flows discounted at some interest rate } i$ .

2. Calculate the present worth of the cashflows using the minimum rate of return to discount (or bring back) to the present cashflows that occur in future time periods. This analysis calculates the present worth of the investment, expressed as  $PW_x$  where  $x$  is the percent minimum rate of return, or discount rate. If the  $PW_x$  is positive, it is known that the proposed investment's rate of return is greater than the established minimum. If the  $PW_x$  is negative, it is known that the proposed investment's rate of return is below the established minimum.

Because calculation of the rate of return is an iterative process, it is time consuming for all but the simplest cashflows. Calculation of the  $PW_x$  is relatively straightforward and returns a quick go or no-go decision on the proposed investment.

**Example 4**

The management of the company in Example 1 has established a minimum rate of return of 12% for all projects. Should the new drill press be purchased? First, set up the equation as shown in Figure 1.2.3. Note that cashflows out of the company are, by convention, expressed as negative numbers, and cashflows into the company are expressed as positive numbers. Since the  $PW_{12}$  of -\$8102 is negative, the proposed new drill press does not meet the company's required investment criteria, and the press should not be purchased. Many investment decisions are analogous to the preceding example; the key to accurate investment analysis is to correctly identify the applicable cashflows that will result from a proposed investment.

$$PW_{12} = -\$14,500 + \$800(P/A, 12\%, 7) + \$6,800(P/F, 12\%, 8)$$

No multiplier since $t = 0$ .	P/A gives present worth of the cashflow for years 1-7.	P/F gives present worth of the cashflow in year 8.
----------------------------------	---	---

**Figure 1.2.3** Present worth calculation for Example 4.

<sup>4</sup> The danger in this method is that it is sometimes applied without including such effects as quality and employee and customer satisfaction.

### 1.2.4 Machine Cost Determination

There have been countless machines designed to perform tasks in a technically elegant manner. However, only those machines that can operate in a cost-effective manner will become commercial successes.<sup>5</sup> There are two components to the cost of any machine: the fixed cost component and the variable cost component. Fixed costs are defined as those costs that are continually present because the machine is there; thus they occur irrespective of whether the machine is producing products. Examples of fixed costs include: cost of required spare parts inventories, certain maintenance costs, and cost of floor space. Variable costs are costs incurred that are directly related to the amounts of product produced. Examples of variable costs include: material, labor, most maintenance costs, and utilities (i.e., power) used by the machine. The task of comparing various alternative machines is mathematically simple, consisting generally of addition, subtraction, and multiplication of the various cost components. The difficult part of the problem is identifying which cost components are relevant to a given situation and developing realistic estimates of production rates, wages, interest rates, taxation rules, and so on.

#### *Initial Capital Expenditure*

Initial capital expenditures are the up-front costs associated with placing a given piece of machinery into service. There are numerous expenses to consider, many of which are easily overlooked by engineers in the early stages of design. Nonetheless, they are real costs that will be included in evaluations by potential purchasers. Examples of initial capital expenditures include:

- Cost of the machine itself.
- Cost of freight and rigging; machines that are oversized to the point of not being truckable on a standard-size truck may incur significant extra shipping costs.
- Cost of spare parts inventory.
- Cost of training employees to operate and maintain the machine.
- Cost of physical plant modifications, such as power sources, structural changes to accommodate weight, size, vibration, noise, and so on.

Awareness of these factors can help a design engineer to minimize a machine's associated costs. In many cases this can be done without changing the machine's basic design or increasing its cost. For example, if one is designing a large electric-powered press that utilizes an innovative method of high-speed operation, the design engineer can:

- Make the machine so that it comes apart into major subassemblies for ease of shipping and installation.
- Utilize gearboxes, motors, and other general components that are also used on other machines of this type. This reduces the purchaser's need to develop another entire supply of spare parts for the machine, and may simplify the purchaser's training expenses for repair technicians. For instance, if research shows that 75% of presses use "Brand X" motors with "Brand D" speed controllers, there is some merit in this machine also doing so, unless there is a sound technical or economic reason to do otherwise.
- Utilize control logic systems similar to other machines of this type, unless there is a sound technical or economic reason to do otherwise. This will reduce operator training expenses associated with the machine.
- Design the component parts' layout for serviceability and operator comfort and safety.

For this example, the cost of implementing these suggestions would probably be small, yet they may result in a more economical machine design than, for instance, a press that requires double-wide trucks for transport, has many hard-to-find motors and gearboxes, and has an operator control system unlike most other machines of its type.

#### *Fixed Maintenance Costs*

Fixed maintenance costs are costs to maintain the machine that are not dependent upon the volume of production. For example, if the lubrication oil must be changed "every month or 250 hours of operation," the cost to do so is a fixed maintenance cost, assuming that the machine is used on a 5-day-per-week, single-shift production schedule. In general, fixed maintenance costs are not as significant as variable maintenance costs for machines that are in relatively constant use.

<sup>5</sup> "A hen is only an egg's way of making another egg." Samuel Butler

For machines intended primarily for standby use, such as emergency generators and other backup systems, the fixed maintenance costs are usually greater than variable costs.

#### *Variable Maintenance Costs*

Variable maintenance costs are directly dependent on the amount of usage a machine receives. Items such as belt, cutting tool and electric motor brush changes are examples of variable maintenance costs. In the example of the preceding paragraph, if it is assumed that the machine will be used on a two-shift-per-day basis (double shift), the cost of lube oil changes can become a variable maintenance cost.

#### *Capital Asset Depreciation*

As a machine ages, it generally wears out and loses value. *Depreciation* is an accounting term for the cost of the wearing out per year. It is important to note that from the standpoint of cashflows, a company will generally spend the cash at the time of machine purchase. On the other hand, the depreciation charge occurs over a set number of years known as the *recovery period*.<sup>6</sup> There is, in effect, a cash inflow in each of those years because the depreciation charge is not an actual cash outflow. On the contrary, the depreciation charge reduces a company's taxes by the amount of the depreciation charge multiplied by the company's marginal tax rate.<sup>7</sup> There are many methods of calculating exactly how much depreciation to charge in a given year. For simplicity, only the commonly used *straight line method* will be considered here. This method assumes that the machine "wears out" (i.e., depreciates) an equal amount during each year of the recovery period. Thus the annual depreciation charge for an investment is equal to

$$\text{depreciation} = \frac{\text{initial capital expenditure}}{\text{investment recovery period}} \quad (1.2.7)$$

#### *Product Reject Rate*

Inasmuch as reject rates directly affect costs, they must be considered when determining a machine's economic feasibility. There are several potential areas of cost impact:

- Material wasted by the reject.
- Damage to other parts caused by the reject. For example, in the case of a robotic microchip installer, an error in gripper position may damage the circuit board that it is working on. If the circuit board is nearing completion, the damage may cost several thousand dollars. Some complex parts, such as turbine rotors, have millions of dollars of value-added worth.
- Downtime caused by the reject. In the case of a stand-alone lathe, the downtime costs may be minimal. In the case of an assembly line robot, downtime costs can be substantial if the entire line must be stopped to correct the error.

Machine design engineers must thus be aware of the operating characteristics of the market for which their machine is intended.

#### *Ripple Effects*

The maintenance period and operating characteristics of the machine should be considered with respect to other machines in a plant, and the effect of any resultant interdependency. If a shop buys a numerically controlled (NC) lathe to manufacture 1000 gadgets per day, but the shop's stockroom can only supply stock cut to length for 500 parts, additional machinery and equipment will have to be purchased and figured into the cost of using the new lathe. Similarly, if a high price is paid for a new machine that requires little maintenance, but the machine is used to finish parts made on an old machine that often breaks down, the new machine could be idle as a result of another machine's faults. On the other hand, if a new machine is made too cheaply and often needs repairs, it may quickly obtain a bad reputation as a plant stopper and will be shunned by buyers.

#### *Other Tax Considerations*

There are very few investment decisions that are made without consideration of tax consequences. The machine design engineer should consider these issues when comparing design alternatives. In general, the tax-related factors that most affect an investment decision are:

<sup>6</sup> The 1987 federal tax law specifies various recovery periods for different types of investments. For example, the recovery period for most machinery is 5 years; most commercial buildings have a recovery period of 32.5 years.

<sup>7</sup> Under 1987 federal tax law, the marginal tax rate for corporations with profits over \$100,000 is 36%.

- Capital asset depreciation schedules (recovery periods)
- Investment tax credits
- Overall tax rates

Federal and State taxing authorities frequently attempt to institute social change through adjustments to the tax code, and it is thus constantly changing. A machine design engineer does not need to be an expert in all areas of the code; however, a basic familiarity with the sections of the tax applicable to capital investments is very important.

### 1.2.5 Machine Operator Costs

The task of determining "How much does a machine operator cost?" can be very complex, particularly when factors such as payroll burdens, support personnel, and enforcement of work rules are taken into account. A few of the more common costs that should be included in addition to the basic hourly wage are:

*Payroll Burdens:* These commonly fall into two groups: taxes (such as social security tax and unemployment tax) and employee benefits (such as insurance, paid vacation, retirement benefits, and savings plans). These costs can be significant and it is not uncommon for payroll burdens to equal the worker's basic hourly wage rate.

*Worker Efficiency:* The cost of workers' break times and other nonproductive periods must be reflected into calculations of either "cost per hour" or "productivity per hour."

*Support Personnel:* In many instances the direct efforts of a worker at a machine must be supported by others. For example, a particularly sophisticated machine may require that a special mechanic be on-site to provide service and make adjustments. One mechanic may support, for example, six machines. Thus one-sixth of the mechanic's hourly cost must be included in the cost of the machine's operation. Machines designed with better serviceability and reliability can reduce these types of costs and sometimes make the machine more attractive than an alternative production method.

*Work Rules:* In many instances the tasks that a worker is allowed to do are restricted by work rules, which is particularly true in unionized plants. For example, a machine operator may not be allowed to adjust the belt tension at his machine; he would be required to call a mechanic from the maintenance department. This results not only in the extra cost for a mechanic, but also in the cost of the machine operator waiting for the mechanic to come and do the work. In order to minimize this problem, the machine design engineer can try to make routine maintenance as infrequent as possible.

Thus the engineer attempting to determine the cost of human labor must include a multitude of factors; the problem is rarely as simple as "What is the operator's hourly wage, and how many widgets can she make per hour?" When precise data on a worker's production rate are unavailable, approximate production rates can often be determined by utilizing various standardized estimating manuals.

### 1.2.6 Examples

The task of designing a machine can in effect be equated to the task of defining an end use, determining the costs associated with existing machines and/or humans, and then designing a machine which does the same job for a lower cost. The following example will illustrate how various cost factors can affect a purchase decision for a machine, as well as how omitting certain cost factors can lead to incorrect decisions.

#### *Example 1*<sup>8</sup>

Widget Metalworking Company currently has a number of standard, manually operated lathes. A contract has been awarded to Widget for production of 3000 stainless steel screw-top acid flask covers per month. The contract guarantees that the purchaser will order 3000 tops per month for the next 5 years. The plant currently works single shifts, 7 days per week, 50 weeks per year. The plant engineer has solicited a proposal from Nifty Machine Tools, a maker of numerically controlled lathes, for equipment to help Widget meet these production requirements. Widget's

<sup>8</sup> It is assumed here that Widget, Nifty, and Zipmaster are imaginary companies.

management has established that investment decisions are to be made on the basis of a 12% discount rate.

Working with Widget's engineer, the Nifty sales engineer has developed the cost summary shown in Table 1.2.1. Ignoring tax considerations (for the moment) and Widget's other work load, should Widget purchase a new Nifty lathe?

	Existing lathe	Nifty X100 lathe	Zipmaster lathe
Operator hourly wage	\$25.00	\$25.00	\$25.00
Annual overhaul cost	\$1,500	\$7,500	\$12,000
Routine overhaul cost	\$1,000	\$2,000	\$3,900
Routine overhaul frequency (h)	2,000	5,000	3,750
Capacity tops per hour	8	35	35
Cost per top	\$3.69	\$1.19	\$1.88
Number of tops per year	36,000	36,000	36,000
Machine cost	\$0	(\$490,000)	(\$300,000)
Operator training	(\$500)	(\$12,900)	(\$10,000)
Spare parts	\$0	(\$40,000)	(\$22,000)
Salvage value	\$5,000	\$240,000	\$190,000

**Table 1.2.1** Widget's cost summary.

First, the difference between the variable cost of making a top using a manual lathe and a Nifty lathe must be made. Let  $W_o$  = operator's hourly wage,  $O_a$  = annual overhaul cost,  $O_r$  = routine overhaul cost,  $O_f$  = routine overhaul frequency,  $Q$  = capacity, in tops per hour,  $C$  = cost per top. Then

$$C = \frac{W_o}{Q} + \frac{O_a}{Q \times 8 \text{ hours/day} \times 7 \text{ days/week} \times 50 \text{ weeks/year}} + \frac{O_r}{O_f}$$

Thus, for the old lathe

$$C_{\text{old}} = \frac{\$25}{8 \text{ tops}} + \frac{\$1500}{8 \text{ tops} \times 8 \times 7 \times 50} + \frac{\$1000}{2000} = \$3.6920/\text{top}$$

For the new lathe

$$C_{\text{new}} = \frac{\$25}{35 \text{ tops}} + \frac{\$7500}{35 \text{ tops} \times 8 \times 7 \times 50} + \frac{\$1000}{5000} = \$1.1908/\text{top}$$

Thus the new Nifty lathe could save \$2.5012 per top. Note that it is assumed that material costs and reject rates are identical for both machines. The additional profit to Widget Metalworking Company per year, then, is \$2.5012 per top times the 36,000 tops that are to be made each year, or about \$90,000. In order to determine if this additional profit is worth the required initial capital expenditure, a discounted cashflow analysis is utilized. Let  $CF_x$  be the cashflow in year  $x$ , with  $x = 0$  being the present and  $PW_{12}$  be the present worth using Widget's 12% discount rate. Then, for the new lathe

$$CF_0 = \text{new machine cost} + \text{operator training cost} + \text{spare parts cost} \\ = (-\$490,000) + (-\$12,900) + (-\$40,000) = -\$542,900$$

$$CF_1 = CF_2 = CF_3 = CF_4 = \$90,041$$

$$CF_5 = \$90,000 + \text{salvage value} = \$90,041 + \$240,000 = \$330,041$$

Utilizing the formulas from Section 1.2.2 gives

$$PW_{12} = CF_0 + CF_1 \cdot 4(P/A, 4, 12\%) + CF_5(P/F, 5, 12\%) \\ = (-\$542,900) + \$90,041(3.037) + \$330,041(0.5674) = -\$82,139$$

The negative  $PW_{12}$  indicates that Widget's investment criteria are not met, and purchase of the new lathe cannot be justified.

*Example 2*

Unhappily for the Nifty sales engineer, the up-front costs of his company's machine were too high for Widget to justify the expenditure. The Widget plant engineer then contacted Zipmaster Machine Tool Company; their machine, he was informed, had the same characteristics as Nifty's except those shown in Table 1.2.1. Should Widget purchase the Zipmaster lathe? Analyzing the Zipmaster machine purchase in the same manner as that of Example 1, Widget's engineer found the  $PW_{12}$  to be \$11,377. The number is positive, indicating that Widget's investment criteria are met, and the machine could be purchased.

The lesson to be learned from Examples 1 and 2 is that a machine design engineer faces constant economic tradeoffs. Interestingly, in many cases, making the machine more reliable and durable (which is reflected in a higher salvage value and lower maintenance costs) can result in too high an initial cost to allow the product to sell. In essence, the *time value of money* dictates that repair costs and revenues incurred in the future are worth less (when considered at the present time) than their absolute dollar amount at the time of their projected receipt or expenditure in the future. The farther in the future the projected date of expenditure, the less the impact on investment decisions. One must be strongly cautioned, however, to consider systems of machines where downtime on one machine can cripple an entire line. In these cases, it is often worth the cost to pay for reliability.

A machine design engineer must also review the designs of the existing machinery that performs tasks similar to those his machine is intended to replace or compete with. In cases such as the Nifty lathe, the productivity increase of a new machine is simply not enough to overcome its high initial cost. One solution is to change the basic design to reduce the initial costs, even at the expense of higher maintenance costs during the life of the machine, as Zipmaster presumably did.

*Example 3*

Let us assume that Nifty's machine is produced in the United States, while Zipmaster's is manufactured in Europe. Let us further assume that Widget is a profitable company, paying a marginal tax rate of 42.5% (federal, state, and local). For this example, assume that the tax laws specified that the recovery period and investment tax credit<sup>9</sup> for domestic machines are 4 years and 10%, respectively, and for imported machines 8 years and 0%. How would this affect Widget's decision to purchase a new lathe? For the Nifty machine, the investment tax credit is effectively an outright "rebate" of 10% of the machine's purchase price, or  $\$490,000 \times 10\%$ , or \$49,000. By establishing a recovery period of 4 years, the government is, in effect, allowing Widget to "write off" the value of the Nifty lathe in just 4 years; this is a reduction in taxable annual income of  $(490,000 - 49,000)/4 = \$110,250/\text{year}$ . Because Widget pays a 42.5% tax on its profits, the "reduction" in taxable income results in an annual tax bill that is lower by 42.5% of \$110,250, or \$46,856. *Because Widget is not actually paying out the \$110,250 per year depreciation charge, the net effect is that a positive cashflow of \$46,856 occurs.*

Recalculating the  $PW_{12}$  for the Nifty lathe utilizing the tax rules yields \$109,180. The number is positive, indicating that Widget's investment criteria are met by the Nifty lathe as well. Now the Widget plant engineer is faced with the choice of which machine to purchase. A similar calculation must be made for the Zipmaster machine. Inasmuch as the tax rules mandate a different treatment for imported machinery, the reduction in Widget's taxable income is less and results in a recalculated  $PW_{12}$  of \$68,828. Now the economics show that the Nifty lathe has a higher after-tax present worth, and Widget's decision should be to purchase the Nifty lathe. Tax consequences<sup>10</sup> can play an important role in an investment decision. This is particularly true when comparing machinery to human labor, since tax laws frequently give economic benefits to machinery investments.

<sup>9</sup> An investment tax credit is the percentage of an investment's cost that is credited to the purchasing company's tax bill by the government offering the tax credit. The amount of the tax credit must be subtracted from the initial capital investment amount before dividing by the number of years over which the asset is to be depreciated.

<sup>10</sup> Certain tax practices, such as depreciation, recapture, capitalization of spare parts/training, and so on, have been neglected here in the interest of simplicity. These are all factors which marketing generally takes into account when deciding a pricing strategy.