PART 1

Understanding Money and Its Management

CHAPTER ONE

Engineering Economic Decisions

Uber: The Transportation Service Has Become a Global Brand[1] Travis Kalanick, the founder of Uber, was born in Los Angeles, California, in 1976; he learned to code at an early age and went on to study computer engineering at UCLA but left with a few months to go before graduation. After a couple of startups, he had the financial means and time to create Uber. The story goes that on a snowy night in Paris, Kalanick and his cofounder (Garret Camp) struggled to find a taxi and the idea for a "car-on-demand" app was born out of their frustration.[2] Uber Garage was set up in April 2012 and was described as "a workshop where the company will experiment with new ideas for urban transportation."

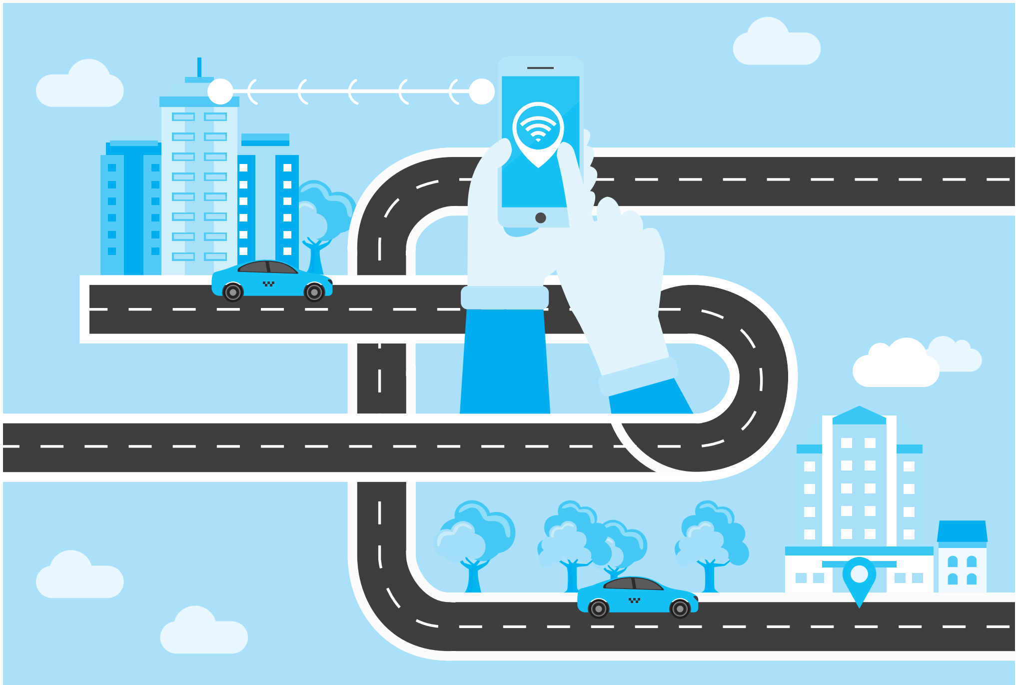
On launching, Uber entered into direct competition with the traditional taxi industry, which was highly fragmented globally. Licenses to operate taxis were generally tightly controlled by local authorities and regulatory bodies; new or additional licenses were not readily granted and no consideration was given to evolving population figures. Existing operators were therefore heavily protected, allowing fares to climb in the absence of free competition. It was ripe for Uber's entry because everybody hates it.[3]

Uber's overriding service aim was to get cars to customers as fast as possible and at the lowest possible price. To do so, it developed a proprietary system and mechanism for managing the volume and flow of vehicles. Essentially, the algorithm tries to predict urban traffic flows based on the existing data and therefore be as accurate as possible in determining where and when customers would need a car. Uber itself extracted a flat 20% commission before paying the driver.

[1] Max Chafkin, "What Makes Uber Run," Fast Company, September 08, 2015. https://www.fastcompany.com/3050250/what-makes-uber-run.

[2] Uber.com/our-story.

[3] IMD, "Uber: An Empire in the Making?," International Institute for Management Development, Lausanne, Switzerland (www.imd.org), Copyright © 2015.



By December 2014, Uber had operations in over 250 cities across the U.S., Central America, Africa, Europe, the Middle East, and Asia Pacific. By the end of 2016, Uber expected to be operating at an annual net booking revenue rate of close to $26 billion.[4]

Another innovation is the introduction of UberPool; this service allows riders heading the same way to share an Uber and save on cost. Kalanick believes that UberPool has the potential to be as affordable as taking a subway, or a bus, or other means of transportation. At a $68 billion valuation on Wall Street, Uber will be bigger than GM, Ford, and Honda. It took Uber only five and a half years to surpass the valuation of 107-year-old General Motors. Does Uber really deserve a higher valuation than the companies that manufacture and sell the bulk of cars around the world? That remains to be seen.

[4] Ibid.

The story of how an engineering student was motivated to invent a transportation service and eventually transform his invention into a multibillion-dollar business is not an uncommon phenomenon in today's market. Companies like Snap, Facebook, Google, Dell, and Microsoft produce computer-related products and have market values of ten to hundred billion dollars. These companies were all founded by highly motivated young college students just like Mr. Kalanick. Also common among these successful businesses is their capable and imaginative engineers who constantly generate sound ideas for capital investment, execute them well, and obtain good results. You might wonder what role these engineers play in making such business decisions: What specific tasks are assigned to these engineers, and what tools and techniques are available to them for making such capital-investment decisions? In this book, we will consider many investment situations, personal as well as business. The focus will be to evaluate engineering projects based on the merits of economic desirability and the respective firm's investment climate.

1.1 The Rational Decision-Making Process

We, as individuals or businesspersons, constantly make decisions in our daily lives. Most are made automatically without realizing that we are actually following some sort of logical decision flowchart. Rational decision making is often a complex process that includes a number of essential elements. This chapter will provide examples of how two engineering students approached their financial and engineering design problems using flexible, rational decision making. By reviewing these examples, we will be able to identify some essential elements common to any rational decision-making process. The first example illustrates how a student named Maria Clark narrowed down her choice between two competing alternatives when financing an automobile. The second example illustrates how a typical engineering design class project idea evolves and how a student named Sonya approached the design problem by following a logical method of analysis.

1.1.1 How Do We Make Typical Personal Decisions?

For Maria Clark, a senior at the University of Washington, the future holds a new car. Her 2008 Kia Sportage has clocked almost 108,000 miles, and she wants to replace it soon. But how to do it—should she buy or lease? In either case, "Car payments would be difficult," says the engineering major, who works as a part-time cashier at a local supermarket. "I have never leased before, but I am leaning toward it this time to save on the down payment. I also don't want to worry about major repairs." For Maria, leasing would provide the warranty protection she wants, along with a new car every three years. On the other hand, she would be limited to driving only a specified number of miles, about 12,000 per year, after which she would have to pay 20 cents or more per mile. Maria is well aware that choosing the right vehicle and the best possible financing are important decisions. Yet, at this point, Maria is unsure of the implications of buying versus leasing.

Establishing the Goal or Objective

Maria decided to research the local papers and Internet for the latest lease programs, including factory-subsidized "sweetheart" deals and special incentive packages. Of the cars that were within her budget, the 2017 Chevy Sonic appeared to be attractive in terms of style, price, and options. Maria decided to visit the dealers' lots to see how the model looked and to take it for a test drive. After having very satisfactory driving experiences, Maria thought that it would be prudent to thoroughly examine the many technical and safety features of the vehicle. After her examination, she concluded that Sonic model would meet her expectation in terms of reliability, safety features, and quality.

Evaluation of Financing Alternatives

Maria estimated that her 2008 Kia Sportage could be traded in for around $5,500. This amount would be just enough to make any down payment required for buying or leasing the new automobile. Since Maria is also considering the option of buying the car, it is even more challenging to determine precisely whether she would be better off buying than leasing. To make a comparison of leasing versus buying, Maria could have considered what she likely would pay for the same vehicle under both scenarios.

- If she would own the car for as long as she would lease it, she could sell the car and use the proceeds to pay off any outstanding loan. If finances were her only consideration, her choice would depend on the specifics of the deal. But beyond finances, she would need to consider the positives and negatives of her personal preferences. By leasing, she would never experience the joy of the final payment—but she would have a new car every three years.
- Through her research, Maria learned that there are two types of leases: open-end and closed-end. The most popular by far was closed-end because open-end leases potentially expose the consumer to higher payments at the end of the lease if the car depreciates faster than expected. If Maria were to take a closed-end lease, she could just return the vehicle at the end of the lease and "walk away" to lease or buy another vehicle; however, she would still have to pay for extra mileage or excess wear or damage. She thought that since she would not be a "pedal-to-the-metal driver," closed-end charges would not be a problem for her.

To get the best financial deal, Maria obtained some financial facts from the dealer on their best offers. With each offer, she added up all the costs of each option due at signing. This sum does not reflect the total cost of either leasing or buying that vehicle over 39 months, as counting routine items such as oil changes and other maintenance are not considered. (See Table 1.1 for a comparison of the costs of both offers. Disposition fee is a paperwork charge for getting the vehicle ready for resale after the lease ends.) The monthly payment for buying option is based on 2.6% APR (annual percentage rate) over 72 months.

- Buy option:
  - Monthly payments: $298 \times 39 = \$11,622$
  - Cash due at signing: $3,572
  - Outstanding loan balance at end of 39 months: $9,475
  - Resale value at end of 39 months: $10,420
  - Total cost: $\$11,622 + \$3,572 + \$9,475 - \$10,420 = \$14,249$
- Lease option:
  - Monthly payments: $219 \times 38 = \$8,322$
  - Cash due at signing: $2,029
  - Disposition fee at lease end: $395
  - Total cost: $\$8,322 + \$2,029 + \$395 = \$10,746$

TABLE 1.1 Financial Data for Auto Buying versus Leasing

Item	Buy	Lease
1. Manufacturer's suggested retail price (MSRP)	$19,845	$19,845
2. Lease length (months)	39	39
3. Allowed mileage (miles)		32,500
4. Monthly payment	$298	$219
5. Mileage surcharge over 48,000 miles		$0.25
6. Disposition fee at lease end		$395
7. Purchase (resale) price of the vehicle at the end of lease	$10,420	$10,420
8. Outstanding loan balance at end of 39 months	$9,475	
9. Total due at signing:		
• First month's lease payment		$219
• Down payment	$3,572	$1,910
• Refundable security deposit		
Total	**$3,572**	**$2,029**

Maria was leaning toward taking the lease option as it appeared that by leasing, Maria could save about $3,503(=\$14,249 - \$10,746)$. However, if she were to drive any additional miles over the limit, her savings would be reduced by 25 cents for each additional mile driven. Maria would need to drive 14,012 extra miles over the limit in order to lose all the savings. Because she could not anticipate her exact driving needs after graduation and it was difficult to come up with $3,572 due at signing, she eventually decided to lease the vehicle.

Review of Maria's Decision-Making Process

Did Maria make the correct decision? When it comes to buying and leasing, there's no one-size-fits-all answer. We need to carefully consider all of the pro, cons, and costs involved and determine which best fits the individual situation. In no way are we saying what Maria did was a logical way to reach the sound economic decision. As you will see in Chapter 2, if Maria had considered the time value of money in her comparison, the amount of actual savings would be far less than $3,503. Even in many situations, the decision could be favoring the buy option.

Now let us revisit the decision-making process in a more structured way. The analysis can be thought of as including the six steps summarized in Figure 1.1. These six steps are known as the *rational decision-making process*. Certainly, we do not follow all six steps in every decision problem. Some decision problems may not require much time and effort. Quite often, we base our decisions solely on emotional reasons. However, for any complex economic decision problem, a structured framework proves to be worthwhile, which is no exception to Maria's buy versus lease decision.

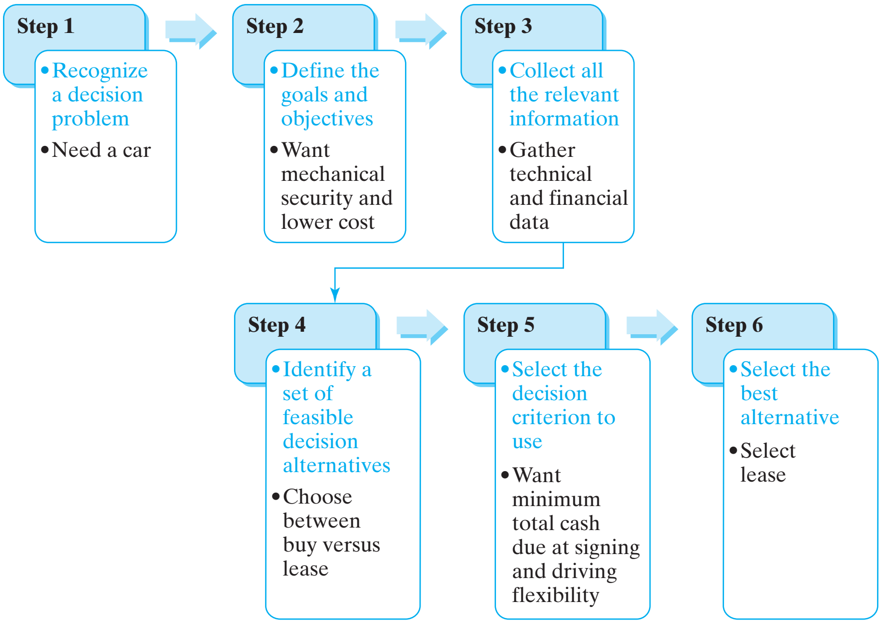


Figure 1.1 Logical steps to follow in a car-financing decision.

1.1.2 How Do We Approach an Engineering Design Problem?

The idea of design and development is what most distinguishes engineering from science, the latter being concerned principally with understanding the world as it is. Decisions made during the engineering design phase of a product's development determine the majority of the costs for manufacturing that product. As design and manufacturing processes become more complex, the engineer will increasingly be called upon to make decisions that involve cost. In this section, we provide an example of how engineers move from "concept" to "product." The story of how an electrical engineering student approached her design problem and exercised her judgment has much to teach us about some of the fundamental characteristics of the human endeavor known as *engineering decision making*.[5]

Getting an Idea: Necessity Is the Mother of Invention

Throughout history, necessity has proven to be the mother of invention. Most people abhor lukewarm beverages, especially during the hot days of summer. So, several years ago, Sonya Talton, an electrical engineering student at Johns Hopkins University, had a revolutionary idea—a self-chilling soda can!

Picture this: It is one of those sweltering, muggy August afternoons. Your friends have finally gotten their acts together for a picnic at the lake. Together, you pull out the items you brought with you: blankets, sunscreen, sandwiches, chips, and soda. You

[5] The original ideas for self-chilling soda can were introduced in *1991 Annual Report,* GWC Whiting School of Engineering, Johns Hopkins University. As of this writing, several versions of self-chilling beverage can appeared on the market.

wipe the sweat from your neck, reach for a soda, and realize that it is about the same temperature as the 90°F afternoon. Great start! And, of course, no one wants to go back to the store for more ice! Why does someone not come up with a soda container that can chill itself?

Setting Design Goals and Objectives

Sonya decided to devise a self chilling soda can as the term project in her engineering graphics and design course. The professor stressed innovative thinking and urged students to consider practical, but novel, concepts. The first thing Sonya needed to do was to establish some goals for the project:

- Get the soda as cold as possible in the shortest possible time.
- Keep the container design simple.
- Keep the size and weight of the newly designed container similar to that of the traditional soda can. (This factor would allow beverage companies to use existing vending machines and storage equipment.)
- Keep the production costs low.
- Make the product environmentally safe.

Evaluating Design Alternatives

With these goals in mind, Sonya had to think of a practical, yet innovative, way of chilling the can. Ice was the obvious choice—practical, but not innovative. Sonya had a great idea: What about a chemical ice pack? Sonya asked herself what would go inside such an ice pack. The answer she came up with was ammonium nitrate (NH_4NO_3) and a water pouch. When pressure is applied to the chemical ice pack, the water pouch breaks and mixes with the NH_4NO_3, creating an endothermic reaction (the absorption of heat). The NH_4NO_3 draws the heat out of the soda, causing it to chill (see Figure 1.2). How much water should go in the water pouch? After several trials involving different amounts of water, Sonya found that she could chill the soda can from 80°F to 48°F in a three-minute period using 115 mL of water. Next, she needed to determine how cold a refrigerated soda gets as a basis for comparison. She put a can in the fridge for two days and found that it chilled to 41°F. Sonya's idea was definitely feasible. But was it economically marketable?

Gauging Product Cost and Price

In Sonya's engineering graphics and design course, the professor emphasized the importance of marketing surveys and benefit–cost analyses as ways to gauge a product's potential and economic feasibility. To determine the marketability of her self-chilling soda can, Sonya surveyed approximately 80 people. She asked them only two questions: (1) How old were they? and (2) How much would they be willing to pay for a self-chilling can of soda? The under-21 group was willing to pay the most, 84 cents, on average. The 40-plus bunch wanted to pay only 68 cents, on average. Overall, members of the entire surveyed group would be willing to spend 75 cents for a self-chilling soda can. (This poll was hardly a scientific market survey, but it did give Sonya a feel for what would be a reasonable price for her product.)

The next hurdle was to determine the existing production cost of one traditional can of soda. Also, how much more would it cost to produce the self-chiller? Would it be profitable? She went to the library, and there she found the bulk cost of the chemicals

Figure 1.2 Conceptual design for self-chilling soda can.

and materials she would need. Then she calculated how much money would be required for production of one unit of soda. She could not believe it! It would cost only 12 cents to manufacture (and transport) one can of soda. The self-chiller would cost 2 or 3 cents more. That was not bad, considering that the average consumer was willing to pay up to 25 cents more for the self-chilling can than for the traditional one that typically costs 50 cents.

Considering Green Engineering

The only two constraints left to consider were possible chemical contamination of the soda and recyclability. Theoretically, it should be possible to build a machine that would drain the solution from the can and recrystallize it. The ammonium nitrate could then be reused in future soda cans; in addition, the plastic outer can could be recycled. Chemical contamination of the soda, however, was a big concern. Unfortunately, there was absolutely no way to ensure that the chemical and the soda would never come in contact with one another inside the cans. To ease consumer fears, Sonya decided that a color or odor indicator could be added to alert the consumer to contamination if it occurred.

What Is the Next Step?

What is Sonya's conclusion? The self-chilling beverage container (can) would be a wonderful technological advancement. The product would be convenient for the beach, picnics, sporting events, and barbecues. Its design would incorporate consumer convenience while addressing environmental concerns. It would be innovative, yet inexpensive, and it would have an economic as well as a social impact on society. Sonya would explore the possibility of patent application of her idea.[6] In the meantime, she would shop for any business venture capitalist who would be interested in investing money to develop the product.

1.1.3 What Makes Economic Decisions Different from Other Design Decisions?

Economic decisions are fundamentally different from the types of decisions typically encountered in engineering design. In a design situation, the engineer uses known physical properties, the principles of chemistry and physics, engineering design correlations, and engineering judgment to arrive at a workable and optimal design. If the judgment is sound, the calculations are done correctly, and we ignore potential technological advances, the design is time invariant. In other words, if the engineering design to meet a particular need is done today, next year, or in five years' time, the final design will not need to change significantly.

In considering economic decisions, the measurement of investment attractiveness, which is the subject of this book, is relatively straightforward. However, information required in such evaluations always involves predicting, or forecasting, product sales, product selling price, and various costs over some future time frame—5 years, 10 years, even 25 years.

All such forecasts have two things in common. First, they are never completely accurate when compared with the actual values realized at future times. Second, a prediction or forecast made today is likely to be different than one made at some point in the future. It is this ever-changing view of the future that can make it necessary to revisit and even alter previous economic decisions. Thus, unlike engineering design outcomes, the conclusions reached through economic evaluation are not necessarily time invariant. Economic decisions have to be based on the best information available at the time of the decision and a thorough understanding of the uncertainties in the forecasted data.

1.2 The Engineer's Role in Business

What role do engineers play within a firm? What specific tasks are assigned to the engineering staff, and what tools and techniques are available to it to improve a firm's profits? Engineers are called upon to participate in a variety of decision-making processes ranging from manufacturing and marketing to finances. We will restrict our focus here to various economic decisions related to engineering projects. We refer to these decisions as **engineering economic decisions**.

1.2.1 Making Capital-Expenditure Decisions

In manufacturing, engineering is involved in every detail of producing goods, from conceptual design to shipping. In fact, engineering decisions account for the majority (some say 85%) of product costs. Engineers must consider the effective use of fixed capital assets such as buildings and machinery. One of the engineer's primary tasks is to plan for the acquisition of equipment (**capital expenditure**) that will enable the firm to design and manufacture products economically (see Figure 1.3).

[6]As of this printing, Sonya's invention has not been yet made to consumer market. However, a high-tech, $20 million plant that will produce self-chilling beverage cans and employ 250 people is earmarked for property on the East Side, Youngstown, Ohio (http://businessjournaldaily.com/20m-chill-can-tech-plant-coming-to-city/).

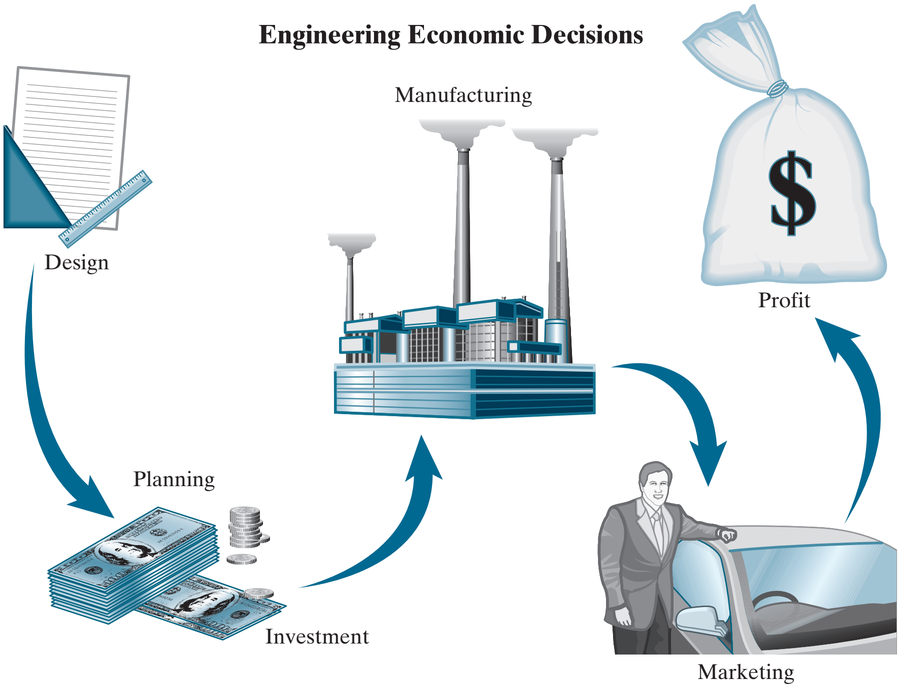


Figure 1.3 One of the primary functions of engineers: Making capital-budgeting decisions.

With the purchase of any fixed asset—equipment, for example—we need to estimate the profits (more precisely, the cash flows) that the asset will generate during its service period. In other words, we have to make capital-expenditure decisions based on predictions about the future. Suppose, for example, that you are considering the purchase of a deburring machine to meet the anticipated demand for hubs and sleeves used in the production of gear couplings. You expect the machine to last 10 years. This purchase decision thus involves an implicit 10-year sales forecast for the gear couplings, which means that a long waiting period will be required before you will know whether the purchase was justified.

An inaccurate estimate of asset needs can have serious consequences. If you invest too much in assets, you incur unnecessarily heavy expenses. Spending too little on fixed assets is also harmful, because your firm's equipment may be too obsolete to make products competitively; without an adequate capacity, you may lose a portion of your market share to rival firms. Regaining lost customers involves heavy marketing expenses and may even require price reductions or product improvements, both of which are costly.

1.2.2 Large-Scale Engineering Economic Decisions

The economic decisions that engineers make in business differ very little from those made by Sonya in designing the self-chilling soda can, except for the scale of the concern. In the development of any product, a company's engineers are called upon to translate an idea into reality. A firm's growth and development depend largely upon a constant flow of ideas for new products, and for the firm to remain competitive, it has to make existing products better or produce them at a lower cost. We will present an

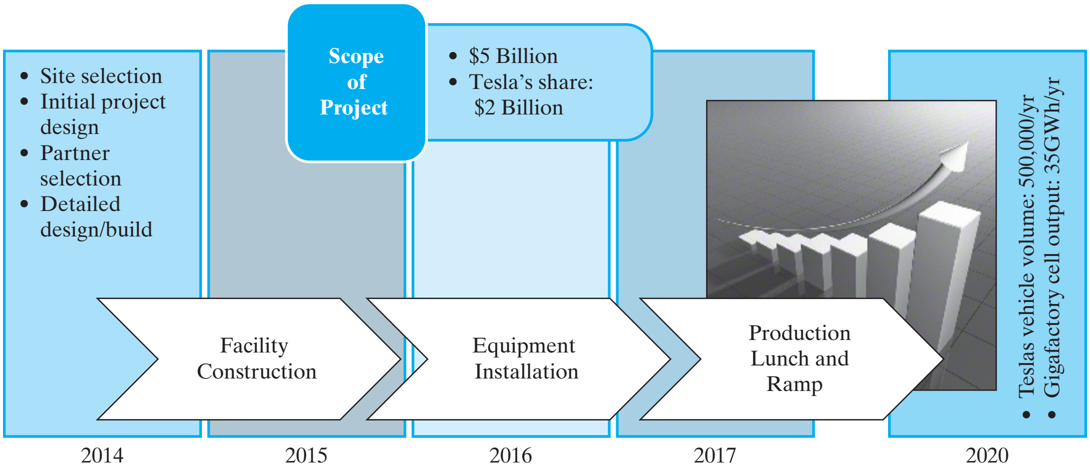


Figure 1.4 Projected timeline of Tesla's Gigafactory.

example of how a large-scale engineering project evolves and what types of financial decisions have to be considered in the process of executing such a project.

Are Tesla's Plans for a Gigafactory[7] Realistic?

Tesla Motors introduced the world's first luxury electrical vehicles whose engines cut air pollution to zero and boost operating efficiency to significant levels. Tesla, in short, wanted to launch and dominate a new "green" era for automobiles and plans to build one of the world's largest factories of any kind in the U.S. But it wouldn't build its electric cars there—it would make the batteries to power them. Tesla's mission is to accelerate the world's transition to sustainable energy. As shown in Figure 1.4, Tesla broke ground on the $5 billion Gigafactory in June 2014, outside Sparks, Nevada, and expects to begin battery cell production by the end of 2017. By 2018, the Gigafactory will reach full capacity and produce more lithium-ion batteries annually than what were produced worldwide in 2013. It says the scale will help drive the cost of batteries down, thereby helping them reach the mass manufacturing target.

How Economical Is Tesla's Plan?

Obviously, this level of an engineering decision is far more complex and more significant than a business decision about when to introduce a new product. Projects of this nature involve large sums of money over long periods of time, and it is difficult to estimate the magnitude of economic benefits in any precise manner. Even if we can justify the project on economic reasoning, how to finance the project is another issue. Any engineering economic decision pertaining to this type of a large-scale project will be extremely difficult to make.

How Much Would It Cost?

Tesla's Gigafactory is so big, in fact, that it will be the world's largest building by footprint. The biggest question remaining about the mass production of the electric vehicles

[7] Tesla Motors Corporation (https://www.tesla.com/gigafactory).

is battery production cost. Costs would need to come down for Tesla's electric cars to be competitive around the world, where gasoline prices are stable. Economies of scale would help as production volumes increase, but further advances in engineering also would be essential. With the initial engineering specification, Tesla has designed the powerpacks and their associated circuitry, each of them contains up to 7,000 standard lithium-ion cells of the sort found in laptops. The firm is said to buy more of these sorts of cells than all the world's computer makers combined. Tesla argues that its battery packs, including their power-management and cooling systems, currently cost less than $300 a kilowatt-hour (kWh) of storage capacity, about half the costs of its rivals.

The Gigafactory, which will eventually turn out batteries for 500,000 vehicles, should cut their costs by another 30%; two-thirds of that saving will come from scale alone, with the rest due to improved manufacturing technology. When costs drop below $200/kWh, battery-powered cars start to become competitive with conventional ones without government subsidies. The Gigafactory could bring Tesla close to that. The lowered cost of the batteries will enable the company to price its Model 3 at about $35,000.

What Is the Business Risk?

Although engineers at Tesla claim that they would be able to cut its current battery costs drastically, many financial analysts are skeptical as raw materials account for 70% of the price of a lithium battery. This would make the scope for savings limited, and even if the factory does turn out many cheap battery cells, it may not be enough. Technically, the key to increasing range and performance is to improve the efficiency, size, and price of the electronics that manage the power, along with overall vehicle weight. Tesla does not have the same advantages in these areas as it has with its batteries. Who is right? Nobody knows for sure at this point.

At a cost of $5 billion, which Tesla will share with Panasonic of Japan, its current battery supplier, and other partners, the Gigafactory is a big gamble. Also, if electric-car demand stalls, the question is what we do with the huge output of cheap batteries. There is a lot of cost that can be removed at larger scales of battery manufacturing, but it's all about the capacity utilization. A battery plant that is not running will cost Tesla a fortune.

Despite Tesla management's decision to build the giant battery factory, the financial analysts were still uncertain whether there would be enough demand. Furthermore, competitors, including U.S. automakers, just did not see how Tesla could achieve the economies of scale needed to produce electric cars at a profit. The primary advantage of the design, however, is that the electric vehicle could cut auto pollution to a zero level. This is a feature that could be very appealing at a time when government air-quality standards are becoming more rigorous and consumer interest in the environment is getting stronger. However, in the case of the Tesla products, if a significant reduction in production cost never materializes, demand might remain insufficient to justify the investment in the battery factory.

1.2.3 Impact of Engineering Projects on Financial Statements

Engineers must also understand the business environment in which a company's major business decisions are made. It is important for an engineering project to generate profits, but the project also must strengthen the firm's overall financial position. How do we measure Tesla's success in the battery project? Will enough batteries be produced, for example, to generate sufficient profits? While the Gigafactory will be of another level of engineering achievement, the bottom-line concern is its financial performance over the long run.

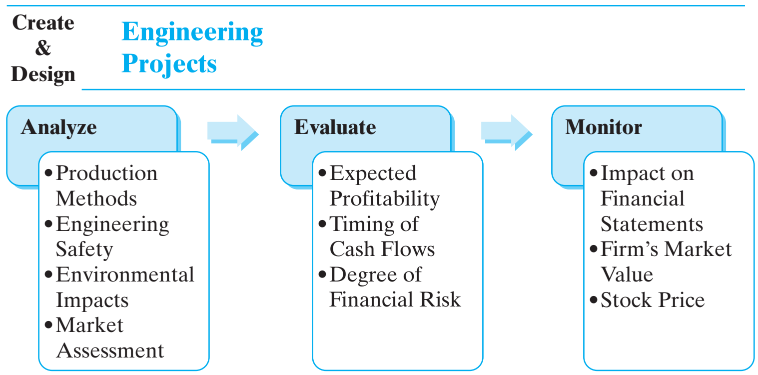


Figure 1.5 How a successful engineering project affects a firm's market value.

Regardless of the form of a business, each company has to produce basic financial statements at the end of each operating cycle (typically, a year). These financial statements provide the basis for future investment analysis. In practice, we seldom make investment decisions based solely on an estimate of a project's profitability because we must also consider the project's overall impact on the financial strength and position of the company. For example, some companies with low cash flow may be unable to bear the risk of a large project like Tesla's Gigafactory even if it might be profitable (see Figure 1.5).

Suppose that you are the president of Tesla. Also suppose that you hold some shares in the company, which makes you one of the company's many owners. What objectives would you set for the company? One of your objectives should be to increase the company's value to its owners (including yourself) as much as possible. While all firms operate to generate profit, what determines the market value of a company are not profits, per se, but rather, cash flows. It is, after all, the available cash that determines the future investments and growth of the firm. The market price of your company's stock to some extent represents the value of your company. Multiple factors affect your company's market value: present and expected future earnings, the timing and duration of these earnings, and the risks associated with the earnings. Certainly, any successful investment decision will increase a company's market value. Stock price can be a good indicator of your company's financial health and may also reflect the market's attitude about how well your company is managed for the benefit of its owners.

If investors like the battery project, the result will be an increased demand for the company's stock. This increased demand, in turn, will cause stock prices, and hence, shareholder wealth, to increase. Any successful investment decision on the battery's scale will tend to increase a firm's stock prices in the marketplace and promote long-term success. Thus, in making a large-scale engineering project decision, we must consider the project's possible effect on the firm's market value. (We will consider this important issue in Chapter 13.)

1.3 Types of Strategic Engineering Economic Decisions

A project idea such as constructing a battery plant can originate from many different levels in an organization. Since some ideas are good, while others are not, it is necessary to establish procedures for screening projects. Many large companies have a specialized project analysis division that actively searches for new ideas, projects, and ventures. Once project ideas are identified, they are typically classified as (1) new products or product expansion, (2) equipment and process selection, (3) cost reduction, (4) equipment replacement, or (5) service or quality improvement. This classification scheme allows management to address key questions such as the following: Can the existing plant be used to achieve the new production levels? Does the firm have the capital to undertake this new investment? Does the new proposal warrant the recruitment of new technical personnel? The answers to these questions help firms screen out proposals that are not feasible.

The Tesla's battery project represents a fairly complex engineering decision that required the approval of top executives and the board of directors. Virtually all big businesses at some time face investment decisions of this magnitude. In general, the larger the investment, the more detailed the analysis required to support the expenditure. For example, expenditures to increase the output of existing products or to manufacture a new product would invariably require a very detailed economic justification. Final decisions on new products and marketing decisions are generally made at a high level within the company. On the other hand, a decision to repair damaged equipment can be made at a lower level within a company. In this section, we will provide many real examples to illustrate each class of engineering economic decision. At this point, our intention is not to provide a solution for each example but to describe the nature of decision-making problems a typical engineer might face in the real world.

1.3.1 New Products or Product Expansion

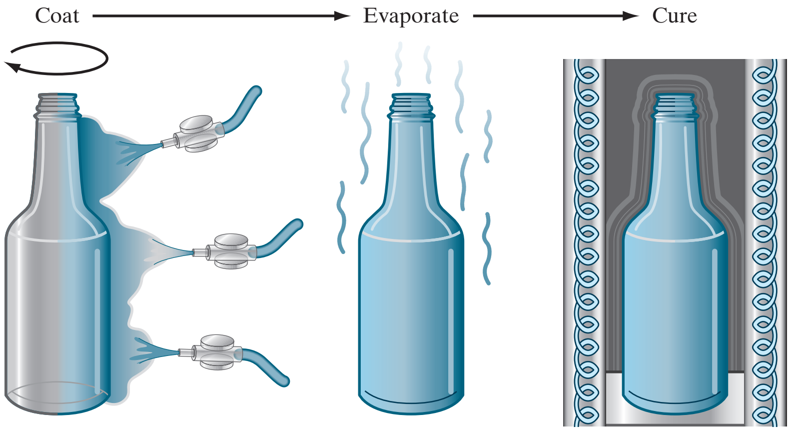
Investments in this category are those that increase the revenues of a company if output is increased. There are two common types of expansion decision problems. The first type includes decisions about expenditures to increase the output of existing production or distribution facilities. In these situations, we are basically asking, "Shall we build or otherwise acquire a new facility?" The expected future cash inflows in this investment category are the revenues from the goods and services produced in the new facility.

The second type of decision problem includes the consideration of expenditures necessary to produce a new product or to expand into a new geographic area. These projects normally require large sums of money over long periods. For example, Apple Computer's investment in iPad®'s A4 chip is estimated to be $1 billion. In 2017, Apple introduced an iPad with a whopping 12.9-inch display to bridge the gap between tablets and laptops. The new A9X chip (an advanced version of A4 chip) is about as powerful as a mid-range laptop, and the unit component cost is estimated to be around $40. The iPad Pro starts at $799 and can range all the way up to $1,129 for the 256 GB model with data connectivity. The cost for Apple to build the $799 base model iPad is estimated to be $366.50.

Clearly, the profit margin for the iPad varies with the different design features—the high-end product being more profitable. At the time of its introduction, the main question was, "Will there be enough demand for the iPad so that Apple could recoup the investment and be the market leader in the tablet PC market?"

1.3.2 Equipment and Process Selection

This class of engineering decision problem involves selecting the best course of action when there are several ways to meet a project's requirements. Which of several proposed items of equipment shall we purchase for a given purpose? The choice often hinges on which item is expected to generate the largest savings (or return on the investment). The choice of material will dictate the manufacturing process involved.



Spray coating of external PET bottles

	Five-Layer Bottle	Three-Layer with External Coating
• Capacity	20,000 bottles/hour	20,000 bottles/hour
• Capital investment	$10.8 million	$7.5 million
• Direct manufacturing cost	$59.35/1,000 bottles	$66.57/1,000 bottles

Figure 1.6 Making plastic beer bottles by two different manufacturing processes.

(See Figure 1.6 on making a 0.5 liter polyethylene terephthalate (PET) barrier beer bottle.) Many factors will affect the ultimate choice of the material, and engineers should consider all major cost elements, such as machinery and equipment, tooling, labor, and material. Other factors may include press and assembly, production and engineered scrap, the number of dies and tools, and the cycle times for various processes.

1.3.3 Cost Reduction

A cost-reduction project attempts to lower a firm's operating costs. Typically, we need to consider whether a company should buy equipment to perform an operation now done manually or in some other way spend money now in order to save more money later. The expected future cash inflows from this investment are savings resulting from lower operating costs. Or perhaps the firm needs to decide whether to produce a part for a product in-house or to buy it from a supplier to reduce the total production cost. This is commonly known as a *make-or-buy* (or *outsourcing*) *analysis*.

1.3.4 Equipment Replacement

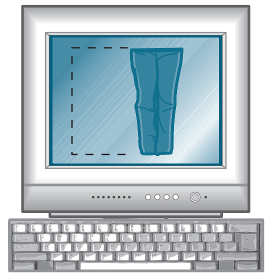
This category of investment decision involves considering the expenditure necessary to replace worn-out or obsolete equipment. For example, a company may purchase 10 large presses with the expectation that it will produce stamped metal parts for 10 years. After five years, however, it may become necessary to produce the parts in plastic, which would require retiring the presses early and purchasing plastic-molding machines. Similarly, a company may find that, for competitive reasons, larger and more accurate parts are required, which will make the purchased machines obsolete earlier than expected.

1.3.5 Service or Quality Improvement

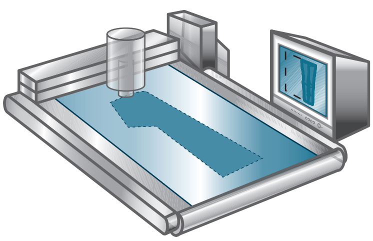
The service sector of the U.S. economy dominates both gross domestic product (GDP) and total employment. It is also the fastest growing part of the economy and the one offering the most fertile opportunities for productivity improvement. For example, service activities now approach 80% of U.S. employment, far outstripping sectors such as manufacturing (14%) and agriculture (2%). New service activities are continually emerging throughout the economy as forces such as globalization, e-commerce, and environmental reuse concerns create the need by businesses for ever more decentralization and outsourcing of operations and processes.

Investments in this category include any activities to support the improvement of productivity, quality, and customer satisfaction in the service sector, such as in the financial, healthcare, and retail industries. See Figure 1.7 for an example of a service improvement in retail where a blue jeans manufacturer is considering installing robotic tailors.

A sales clerk measures the customer, using instructions from a computer as an aid.



The clerk enters the measurements and adjusts the data, according to the customer's reaction to the samples.



The final measurements are relayed to a computerized fabric cutting machine at the factory.

Bar codes are attached to the clothing to track it as it is assembled, washed, and prepared for shipment.

Figure 1.7 To make customized blue jeans for women, a new computerized system is being installed at some retail stores, allowing women to place customized orders.

The manufacturer's main problem is to determine how much demand the women's line would generate: How many more jeans would the manufacturer need to sell to justify the cost of additional tailors? This analysis should involve a comparison of the cost of operating additional robotic tailors with additional revenues generated by increased jeans sales.

1.4 Fundamental Principles in Engineering Economics

This book focuses on the principles and procedures for making sound engineering economic decisions. To the first-time student of engineering economics, anything related to money matters may seem quite strange compared with other engineering subjects. However, the decision logic involved in problem solving is quite similar to any other engineering subject matter; there are basic fundamental principles to follow in any engineering economic decision. These principles unite to form the concepts and techniques presented in the text, thereby allowing us to focus on the logic underlying the practice of engineering economics.

The four principles of engineering economics are as follows:

- **Principle 1: An earlier dollar is worth more than a later dollar.** A fundamental concept in engineering economics is that money has a time value associated with it. Because we can earn interest on money received today (compound interest), it is better to receive money earlier than later. This concept will be the basic foundation for all engineering project evaluation. As noted by Albert Einstein, the most powerful force in the universe is compound interest.
- **Principle 2: All that counts is the differences among alternatives.** An economic decision should be based on the differences among the alternatives considered. All that is common is irrelevant to the decision. Certainly, any economic decision is no better than any one of the alternatives being considered. Therefore, an economic decision should be based on the objective of making the best use of limited resources. Whenever a choice is made, something is given up. The *opportunity cost* of a choice is the value of the best alternative given up.
- **Principle 3: Marginal revenue must exceed marginal cost.** Any increased economic activity must be justified based on the following fundamental economic principle: Marginal revenue must exceed marginal cost. Here, the marginal revenue is the additional revenue made possible by increasing the activity by one unit (or a small unit). Similarly, marginal cost is the additional cost incurred by the same increase in activity. Productive resources, such as natural resources, human resources, and capital goods available to make goods and services, are limited. People cannot have all the goods and services they want; as a result, they must choose resources that produce with the best economy.
- **Principle 4: Additional risk is not taken without expected additional return.** For delaying consumption, investors demand a minimum return that must be greater than the anticipated rate of inflation or than any perceived risk. If they do not see themselves receiving enough to compensate for anticipated inflation and perceived investment risk, investors may purchase whatever goods they desire ahead of time or invest in assets that would provide a sufficient return to compensate for any loss from inflation or potential risk.

These four principles are as much statements of common sense as they are theoretical principles. They provide the logic behind what follows in this book. We build on the principles and attempt to draw out their implications for decision making. As we continue, try to keep in mind that while the topics being treated may change from chapter to chapter, the logic driving our treatment of them is constant and rooted in these four fundamental principles.

SUMMARY

- This chapter provides an overview of a variety of engineering economic problems that commonly are found in the business world. We examined the place of engineers in a firm, and we saw that engineers play an increasingly important role in companies, as evidenced in Tesla's development of giant battery factory. Commonly, engineers participate in a variety of strategic business decisions ranging from product design to marketing.
- The term *engineering economic decision* refers to all investment decisions relating to an engineering project. The most interesting facet of an economic decision, from an engineer's point of view, is the evaluation of costs and benefits associated with making a capital investment.
- The five main types of engineering economic decisions are (1) new products or product expansion, (2) equipment and process selection, (3) cost reduction, (4) equipment replacement, and (5) service or quality improvement,
- The factors of time and uncertainty are the defining aspects of any investment project.

SELF-TEST QUESTIONS

1s.1 Which of the following statements is incorrect?
(a) Economic decisions are time invariant.
(b) Time and risk are the most important factors in any investment evaluation.
(c) For a large-scale engineering project, engineers must consider the impact of the project on the company's financial statements.
(d) One of the primary roles of engineers is to make capital expenditure decisions.

1s.2 When evaluating a large-scale engineering project, which of the following items is important?
(a) Expected profitability
(b) Timing of cash flows
(c) Degree of financial risk
(d) All of the above

1s.3 Which of the following statements defines the discipline of engineering economics most closely?
(a) Economic decisions made by engineers.
(b) Economic decisions related to financial assets.
(c) Economic decisions primarily for real assets and services from engineering projects.
(d) Any economic decision related to the time value of money.

1s.4 Which of the following statements is not one of the four fundamental principles of engineering economics?
(a) Receiving a dollar today is worth more than a dollar received in the future.
(b) To expect a higher return on investment, you need to take a higher risk.
(c) Marginal revenue must exceed marginal cost to justify any production.
(d) When you are comparing different alternatives, you must not focus only on differences in alternatives.

PROBLEMS

1.1 Read the *Wall Street Journal* over a one-week period and identify the business investment news using one of the categories—(1) new products or product expansion, (2) equipment and process selection, (3) cost reduction, (4) equipment replacement, or (5) service or quality improvement.

1.2 By reading any business publication give examples that illustrate one of the four fundamental principles of engineering economics.

This page intentionally left blank