APPLIED SYSTEMS ANALYSIS

Engineering Planning and Technology Management

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Plan	Initial cost	Annual benefit
A	200	30
B	600	75

The mayor tells you to assume a 20-year life for the systems and to use a discount rate of 8%.

(a) Calculate the net present value and benefit-cost ratio for each of these designs.

(b) Do you think 8% could correctly reflect the discount rate? Why or why not?

(c) Assuming 8% is the correct opportunity cost, which design should the mayor choose? Discuss the basis for this selection.

13.12. *Criteria Review*

What are the advantages and disadvantages of each of the following criteria:

(a) benefit-cost ratio

(b) net benefit-cost ratio

(c) internal rate of return

(d) net present value

13.13. *Easy Start*

Ready-Tech's sales manager (see Problem 11.10) approaches a lab that uses the two-year payback method of evaluating commitments to new equipment. The lab would have to spend $8000 on space changes to accommodate the machine. They would then save $12,000/yr in labor costs, which, under the $10,000/yr "Regular" lease would give them a net savings of $2000/yr. The lab discount rate may be assumed to be 20%.

(a) What is the lab's payback period under the "Regular" lease? Under the "Easy Start" lease with initial payments of $7000?

(b) Should the lab acquire the machine under "Easy Start?" Discuss your evaluation.

COST ESTIMATION

14.1 THE PROBLEM

Costs are a crucial element in systems analysis. As stressed in Chapter 1, optimal design requires a full consideration of values on a par with the technical aspects. It is meaningless to talk of a best design if one has not factored in costs: as defined by the production function (Chapter 2), there are a multitude of technically efficient combinations that may produce a desired result. Costs or relative values are the means to identify the truly best designs from the many technical candidates. The optimality conditions of Section 4.2 make this point clear: the optimum is defined by an equal weighting of Marginal Products and Marginal Costs.

Despite the importance of costs, engineers and designers tend to minimize their role in systems analysis. This is a natural psychological problem: we all normally focus on the areas we know and disregard the others. Thus it is usual for engineers to imagine simplistically that costs are something you can "look up" or "get from the accountants." This is a fundamental mistake that can have profound consequences.

The fact is that it is difficult to determine the costs to use in a systems analysis. The most obvious figures are likely to be wrong; if they are used the design is almost certainly going to be poor. The problem is to determine the appropriate costs. To do so, a systems analyst must deal with several issues, each discussed in turn in this chapter. These concern:

- *Estimation*, the measurement of the concept
- *Concepts*, the correct idea about what is to be estimated
- *Dynamics*, the variation in costs over time
- *Technological Choice*, the further variation in costs due to fundamental changes in the structure of costs

14.2 ESTIMATION

The answer to the question: "what is the cost of X?" would seem straightforward, even trivial. In everyday life, we are accustomed to determining and comparing the prices of things we want. We typically do not find this difficult; we check the price tags in different stores, read ads in the papers, and so on. It is natural to think that we could easily extend this process to the determination of the costs of steel, computers, trucks, labor, and all the other inputs X to a production process. Unfortunately, this is not the case.

The estimation of costs is complex because they are routinely misstated — from the point of view of a systems analysis. Published costs, either in trade journals or an organization's books of account, suffer systematically from errors of omission and commission. Some elements of costs are normally left out, and others are routinely distorted.

The root cause of these difficulties lies with the accounting system, the formal procedures for keeping track of money in any organization. This system has been constructed for distinct purposes, which it usually accomplishes well. Its goals are, however, quite different from those of systems analysts. This is what makes measurements of costs difficult.

Accounting systems have been designed to keep managers and employees honest. One basic motivation is to account for all receipts and expenses. Accounts are thus meticulous tabulations of all monies received and spent. To facilitate this purpose, accounts use conventional categories of types of expenses — such as payroll, transport, insurance, and so on. This fact is a primary source of the errors of omission — from a system analyst's point of view.

Accounting systems are also designed to present financial situations conservatively. The idea is to counterbalance the managers' tendency to over-state their performance and profits. Accounting systems thus deliberately avoid using subjective appraisals of value. They have, for example, typically excluded inflationary effects and recorded the value of an asset as the price originally paid for it rather than try to represent what it is really worth in the market. In the same vein, accounting systems routinely assume that assets lose value over time. This depreciation is set by standard formulas which easily do not reflect reality. These conventions are the sources of systematic distortions in our estimates of costs for systems analysis.

Errors of omission. Suppose a company pays $500 per ton to a supplier for some material. Superficially, it might appear that this cost per unit must be the marginal cost of that material, the figure that is needed for an optimization. But is it really? Does it include all the factors that represent the cost to the system of acquiring and using a unit of that material?

Normally, the cost entered into the accounts of a company omits many of the elements that constitute the true cost of an item. What about transportation, for instance? If a company's employees pick the material up, the cost of their time, their vehicle, and its fuel should be part of the marginal cost of the item.

So should its insurance and packaging. The difference between the amount that is paid for and what is usable after breakage and theft should also be factored in. Every transaction in an organization must also be serviced by a broad range of people such as purchasing agents and accountants. Their services are part of the cost of an item, as are even their medical expenses and pension rights. All these elements are some part of the marginal cost of an item. The accounting system will deal with them in a variety of categories, quite distinct from that in which the price paid to the supplier is entered. This price simply does not reflect the true marginal cost.

The omissions do not always increase costs. The stated price may not reflect subsequent rebates or discounts for prompt payment. It may not include associated services or other benefits. The true cost of any input depends on all the surcharges and discounts that are an effective part of the price paid to obtain it, but which are buried in the accounting system.

Errors of commission. Consider an agency that acquired property in a city 25 years ago or more. Conventionally, the value of the land in the accounting books will be stated as the amount actually paid; no increase due to inflation would have been incorporated. Thus, even if the increase in real estate prices had been moderate, the true value of the property would be several times its original cost. With only 6% average annual increases in value, the true cost would be over four times higher after 25 years (see the "rule of 72," Section 11.4).

Depreciation as practiced in accounting introduces a comparable form of distortion. The value of buildings and equipment is routinely reduced by formula each year independent of what actually happens to the value of the property (unless it is actually destroyed). Established companies thus usually have substantial assets whose nominal costs are close to zero.

The conclusion to be drawn from this discussion is that systems analysts cannot simply "look up" the costs of the inputs; they cannot rely on the massive data generated by the accounting system to provide them directly with good estimates of the costs they require for optimization. A most careful effort is necessary in order to obtain good estimates of the costs that should be used in the analysis.

14.3 CONCEPTS

Marginal costs are at the heart of a systems analysis, as Chapter 4 indicates. We need to know the incremental effects on total costs of any decision to use resources in a design. This is the key concept in estimating costs.

Determining marginal costs can be confusing. First, one must of course distinguish between historic costs and the future costs that would actually apply to the system being designed. Secondly, it is important to refer to the "opportunity cost" of any use of a resource. This is its total effect on the system and may be quite different from its price. Finally, one has to deal with the complexity of allocating *joint costs*, those that are shared by many items.

Future versus past costs. Future costs are the only ones relevant to future decisions. They are not easy to determine. They can be presumed to be different from the historic costs tabulated in the accounting system. Even after the accounting data have been carefully analyzed to determine the true cost of an item (see Section 14.2), these "*actual costs*" are not immediately relevant; they need to be adjusted to future conditions.

To get estimates of future costs, one must first adjust present or historic costs for inflation and whatever other factors that may occur over time. These forecasts are quite difficult to make accurately, as the example in Section 15.1 emphasizes. Reasonable estimates of current trends in the costs of materials and labor are available, however, in specialized trade publications. The *Engineering News-Record* compiles these estimates for civil engineers, for example. Their series has the merit of projecting unit costs by regions, so that estimators can adapt to the specific local situations that may apply.

Future costs also differ from current costs because we learn to do things better, to avoid past mistakes. The rule of thumb, reflected by the empirical learning curve, is that we may hope for a 10% to 30% reduction in unit costs as the cumulative number of units produced doubles, as indicated in Section 4.5. Naturally, this general phenomenon needs to be validated for any company and any activity. Past trends can be plotted into the learning curve for that activity, and extrapolated into the future.

Opportunity cost versus expense. The "opportunity cost" of an item is its value in the best available alternative. It is the maximum value that must be given up if the resource is used in the project under consideration. Used in this sense, which is traditional, the concept is the same as that used when referring to the "opportunity cost" of capital (see Section 12.3). By definition, the "opportunity cost" of a resource is its true marginal cost, and should be used in the analysis.

> **Semantic caution:** As indicated in Section 12.3, the "opportunity cost" as used in economics does not have the same meaning as in linear programming; it really is the shadow price of that resource (see Sections 6.2 and 6.3).

The opportunity cost of an item is often much higher than its price or the expense of getting it. This is a source of confusion in estimating the true marginal cost: an analyst may focus on the price and neglect the real value.

As an example of the potential difference between the opportunity cost and the price of something, consider a person who wishes to build a home on a piece of land that would sell for $L. The marginal cost of the land is clearly $L if the person has to buy it. But what if the person already has it, perhaps because it was an inheritance? The expense of using it is nothing; there is no outlay of capital for it. But the opportunity cost—and the marginal cost to be used in the analysis—is still $L: if the land is not used for a home, it could be sold for $L and the person using it still gives up $L by devoting the land to construction.

In general, the "opportunity costs" of items often differ substantially from the money paid for them because these prices fail to adjust to actual values. For example, suppose that a particular resource is an especially ingenious designer who is good at reducing manufacturing costs. The opportunity cost of using this designer on some project is the maximum net amount this person would save if used on alternative projects—this could be millions. Theoretically, if really worth this much, a talented designer could negotiate an equivalent salary (perhaps through a capable agent and with free agent status). In practice, the designer's salary is likely to be limited by industry standards and will not reflect true opportunity cost. Operationally, the marginal cost of using the designer on a project is not just that person's salary, it is also the loss of savings to the best alternative project.

Joint costs. Costs that are incurred for the benefit of many different activities are *joint costs*. For example, a university has a president, central staff, and libraries that are concerned with all its activities: education and research in many fields. By definition these costs are not uniquely associated with any one activity.

True marginal costs are difficult to determine whenever there are significant joint costs. There is no clear way to allocate joint costs. How, for instance, should one divide up the cost of operating a university library? Would it be right to do so according to the number of students? Or would this be unfair to the undergraduates who require less of the expensive research journals? Should it be according to the number of books borrowed, regardless of their cost? And so on.

Accounting systems routinely allocate joint costs to activities on the basis of formulas which, although perhaps quite satisfactory for accounting, may be inappropriate for a systems analysis. For example, a common procedure is to allocate joint costs in proportion to revenues.

Thus at MIT the library expenses are largely prorated to the research contracts according to their size; the use by students is minimized. This is a pleasant way to get research contracts to pay for the libraries. But this perspective does not give what the systems analyst needs to know in thinking about increasing student enrollment. The accounting formula does not indicate the true cost on the library systems of additional students. This marginal cost of an action is what is required and is the concept to keep in mind.

14.4 DYNAMICS

The marginal costs of an activity depend on the period under consideration, on whether we are concerned with the short run or the long run. As a general rule, the short run costs do not equal the long run costs.

For many purposes it is sufficient to divide costs into capital costs, C_k, and variable costs, C_v, as was done in Sections 6.6, 13.3, and 13.4. More precisely, costs can be thought of as being fixed, C_f, and variable. The *fixed costs* are all those that cannot be changed at any time. They obviously include the capital

costs invested in the plant, but also the other fixed commitments that cannot be immediately changed, such as leases on equipment and contracts with staff.

The exact content of the fixed costs depends on the period under consideration; the longer the period, the more that can be changed. Leases that must be paid in the short run do not have to be renewed in the longer run, for example. A variety of expenses can thus pass from fixed to variable costs, and this changes the marginal costs over the different periods.

Similarly, the variable costs differ between the short run and the long run. In the short run, production is normally limited by the facilities already in place. This means that it will be difficult, that is expensive, to expand production in the short run. Given a plant of particular size, for example, one can exceed normal production capacity by going to overtime and paying the work force more. The shadow price on the short-term constraints is generally high (see discussion in Sections 3.2 and 6.2). In the long run, however, one would have the opportunity to build extra capacity, to reduce overtime and other costs of congestion, and thus to lower the variable costs.

The effects of the differences in the fixed and variable costs over time typically follow a systematic pattern. This is shown in Figure 14.1: the average cost of making a unit of Y normally rises relatively rapidly either above or below the level of production for which a system is designed. In the longer run, however, the system can be tailored to a higher or lower level of output, and needless expenses can be dropped by closing facilities, or an extra plant can be added to avoid congestion or overtime.
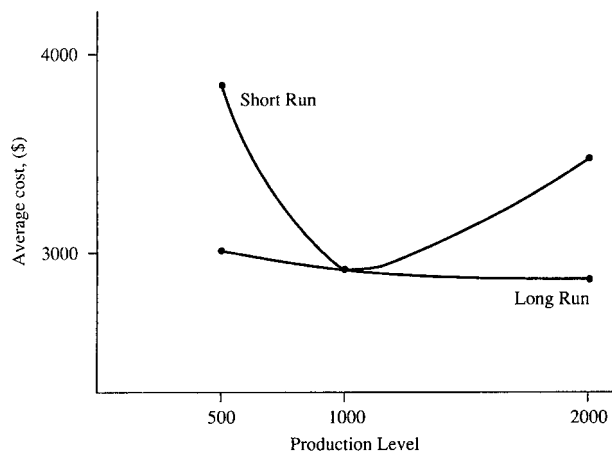

FIGURE 14.1
Typical relation between short- and long-run average costs, as illustrated by example situation.

Long- and Short-Run Costs

Consider a manufacturing system producing units of Y. At any time it has fixed costs of $100,000 for its central staff (president, supervisors, and so on) and $200,000 per warehouse. In its most efficient configuration, it has one warehouse for every 250 units produced. Its variable costs are $2000 per unit of Y up to its design capacity, beyond which they double, due to overtime payments to the workers and other costs of congestion.

To calculate short-run average costs, we have to start from the current situation. Suppose the system is now configured to produce 1000 Y. Its total costs in $ \times 10^3$ are then:

$$C(Y) = 100 + 4(200) + Y(2) + Y'(2)$$

where Y' is the extra production beyond the design level of 1000. The average cost can be calculated by dividing by Y. Doing this for three levels of production we obtain:

	Production level		
	500	**1000**	**2000**
Short run Average cost, ($)	3800	2900	3450

To calculate long-run average costs we have to deal with the state of the system when configured for the appropriate level of production. If this were less than 1000, warehouses would be closed; if it were more, additional ones would be opened and overtime reduced. For example, the total cost for a long-run production of 500 would be:

$$C(Y)_{500} = 100 + 2(200) + Y(2)$$

For 2000 it would be:

$$C(Y)_{2000} = 100 + 8(200) + Y(2)$$

We then have:

	Production level		
	500	**1000**	**2000**
Long run Average cost, ($)	3000	2900	2850

Figure 14.1 compares the above results.

The precise relationship between the short- and long-run costs depends on the specifics of any situation, and must be calculated accordingly. See the box on page 269 for an example.

14.5 TECHNOLOGICAL CHANGE

Long-run, future costs may also differ from either the short-run or historical costs because of technological change. In estimating the cost of a new system we must recognize that we may be dealing with a different production function than we currently face. This naturally leads to a different cost function (see Sections 4.4 and 4.5).

Most obviously, new discoveries will lead to greater efficiencies. Thus, jets replaced piston engines in aircraft, computers replaced mechanical calculators, and fiber optics replace metallic telephone lines.

More subtly, the change in technology will occur because a change in scale will make one technology cheaper on average than another. Typically, as indicated in the discussion of break-even analysis in Section 6.6, higher levels of production will lead to technologies with higher capital cost but lower variable costs. As the amount transported in a region increases, for instance, it may be cheaper to use railroads than highways: the greater traffic compensates for the extra capital cost.

This second kind of difference between long-run and current costs does not require any new technology; it may even revert to an old one, as when subways are built in cities to replace automobile transport. For this reason this kind of technological change may be forgotten by systems designers, when it should not be.

14.6 SUMMARY

Costs, critical parameters of systems analyses, are difficult to estimate. The required figures are not obvious; they are typically buried in accounting data and must be carefully constructed.

There is no simple set of procedures that will yield the correct numbers. To obtain valid estimates one must focus on the essential issue: what is the incremental effect of the proposed changes to the system?

Since systems design is mainly concerned with future projects, analysts should keep in mind the ways costs change over time. In the long run costs are typically more flexible than in the short run as current constraints change. In addition, technological change may alter the possibilities radically.

REFERENCES

ATT Company, (1977). "The Nature of Costs," Chapter 6, *Engineering Economy*, 3rd ed., McGraw-Hill, New York.

Pindyck, R. S., and Rubinfeld, D. L., (1989). "The Cost of Production," Chapter 7, *Microeconomics*, Macmillan, New York.

PROBLEMS

14.1. *Cost Analysis*
Define the fixed, variable, marginal, and average costs for the cost functions:
(a) Cost $= 100 + 24X^2$
(b) Cost $= 100 + 12X + 0.7X^2$

14.2. *Airport Expansion*
An airport authority is expanding its facilities to reduce waiting time for takeoffs and landings, and generally to improve its service. The work costs \$20M of which 20% will be for flight takeoff and landing, 15% for improved passenger flow, 30% for improved freight handling, and 35% for general maintenance and appearance. The airport is used by three airlines whose number of flights, passengers, and tons of freight last year were:

Airline	Flights	Passengers	Freight, tons
A	5000	250,000	600
B	3000	200,000	250
C	2000	50,000	150

What costs would you suggest be charged to each of the airlines for expansion and improvement of the airfield? Justify your answer and explain any assumptions that you have made.

14.3. *Costs of Seasonal Service*
This is an example of a general problem, faced by all producers that face seasonal variations. For specificity we consider an electric power system with the following simplified pattern of use: in 9 months of the year 100 MW of capacity are required; in the remaining 3 months, 150 MW are needed.

Suppose the annual capital cost of building units of capacity is \$5M/year for each 50 MW plant (i.e., \$0.1M per MW); the operating cost is \$0.01M/MW-month; and the annual overhead on the system is \$3M/yr.
(a) What is the average cost per MW-month produced?
(b) What is the average cost per MW-month of producing the base load, that is, the steady use of 100 MW each month?
(c) What is the average cost per MW-month of providing for the peak load of 50 extra MW for each of three summer months?
(d) Suppose that the base use in the off peak period were to increase by 10 MW, while the peak use did not rise. What is the marginal cost to the system of providing these extra 90 MW-months of power?
(e) Suppose the system has to supply 90 MW-months more power evenly during the three peak months, thus requiring 30 MW more capacity. Suppose further that this new capacity will—because of new technology and safety regulations—have a capital cost of \$0.4M/MW annually. How does this affect the cost to the consumer? Discuss.
(f) The situations represented in (d) and (e) are reasonably typical. Discuss the implications for efforts designed to get customers to shift their pattern of use from peak to off-peak.