Low-Cost Solar
Array Project
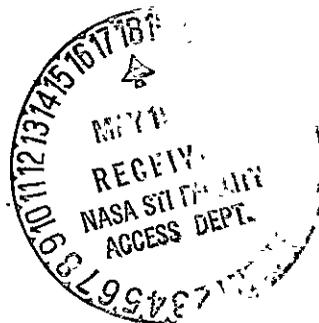
A Normative Price
for a Manufactured Product:
The SAMICS Methodology
Volume II: Analysis

Robert G. Chamberlain

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Abstract

The Solar Array Manufacturing Industry Costing Standards (SAMICS) provide standard formats, data, assumptions, and procedures for determining the price a hypothetical solar array manufacturer would have to be able to obtain in the market to realize a specified after-tax rate of return on equity for a specified level of production.

This document presents the methodology and its theoretical background. It is contended that the model is sufficiently general to be used in any production-line manufacturing environment.

Implementation of this methodology by the Solar Array Manufacturing Industry Simulation computer program (SAMIS III, Release 1) is discussed.

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Figures

Section I

Brief Description of the Methodology

Figure 1 illustrates the most important features of the structure of the SAMICS model and of the sequence of calculations implemented in the SAMIS III computer program (Reference 9).

A. MODEL STRUCTURE

(1) The hypothetical industry contains a collection of firms arranged in a generalized tree* structure. Each firm is a realization** of a company whose characteristics are described by input.

(2) Each firm contains a collection of work stations also arranged in a generalized tree structure. Each work station is based on an input manufacturing process description.

(3) Each process description contains, among other things, a detailed list of direct requirements for facilities, personnel, utilities, materials, and supplies and a list of by-products produced. All of these *expense items* are contained in the *cost account catalog*.

(4) Each entry in the cost account catalog contains the item identifier, an item-specific price versus quantity relationship (possible nonlinear), an item-specific inflation table, and a list of the first-level indirect requirements*** implied by the entry. Relative quantity functions are associated with each indirect requirement on the list. The standard facilities construction and staffing assumptions (Reference 5, Volume II) are implied by the combined effects of all of the first-level indirect requirement relative quantity functions.

B. SEQUENCE OF CALCULATIONS

The rationale for determining product prices is the *required revenue condition*: prices are to be chosen so that company revenues are just sufficient to recover all company expenses (including a specified profit). Since the cost of purchased products is one of the expenses, the prices of those products must have been determined. Therefore, price calcula-

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*Alternatively, the structure can be considered to be a restricted network. The restriction is that there be no loops — it must be possible to order the companies in a list so that suppliers always appear somewhere below the companies they supply.

**That is, there is a one-to-one correspondence between "firms" and "companies." The distinction is simply that all input descriptors (such as *financial leverage* and *rate of return on equity*) are associated with "companies," while calculated results (such as *product price* and annual *return on equity*) are associated with "firms." This distinction is only important in the context of the SAMIS III computer program, and is not always adhered to in this report.

***For example, a *maintenance worker* requires a *maintenance foreman* at the first level of indirect requirements and a *security and maintenance manager* at the second level. The second-level requirement of a *maintenance worker* for a *security and maintenance manager* is accounted for when the first-level requirements of the *maintenance foreman* are considered. Higher-level indirect requirements are accounted for similarly.

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START HERE
INPUT INDUSTRY SIZE

CONVERT BACK TO INDUSTRY SIZE UNITS

⑨ PRICE
END HERE

CONVERT TO PRODUCT AND ALLOCATE TO COMPANIES

① COMPANY ANNUAL PRODUCTION

EXTRACT PRICE OF FINAL PRODUCT AND DEFLATE

⑧ PRICE OF EACH, WORK STATIONS PRODUCT

ALLOCATE OVERHEAD TO WORK STATIONS

⑦ FIRM'S TOTAL ANNUAL EXPENSES

ITERATE ON ANNUAL REVENUE
CORPORATE INCOME TAX
ONE-TIME COSTS
MISCELLANEOUS

COMPANY MODEL

COMPANY PRODUCTS

③ ACCUMULATE FIRM'S DIRECT REQUIREMENTS

INDIRECT REQUIRE-MENTS RELATION-SHIPS

④ FIRM'S TOTAL REQUIREMENTS

STRUCTURE THE PRODUCTION SEQUENCE AND COMPUTE DIRECT REQUIREMENTS

MACHINES
FLOOR SPACE
UTILITIES
PERSONNEL
BY-PRODUCTS
COMMODITIES

INFER TOTAL REQUIREMENTS OF THE FIRM

MACHINES
LAND
FACILITIES
UTILITIES
PERSONNEL
BY-PRODUCTS
COMMODITES
RESOURCES
(INCLUDES ALL INDIRECTS)

APPLY SUBMODELS
INFLATION
CAPITAL REPLACEMENT
DEPRECIATION
INVESTMENT TAX CREDIT
WORKING CAPITAL
INSURANCE
PROPERTY TAXES
RETURN ON EQUITY
INTEREST ON DEBT
ONE-TIME COSTS

⑥ PRICE-INDEPENDENT EXPENSES

CAPITAL EXPENSES
OPERATING EXPENSES
INSURANCE
PROPERTY TAXES
RETURN ON EQUITY
INTEREST ON DEBT

WORK STATIONS

PURCHASED PRODUCTS

FORMAT A PROCESS DESCRIPTION

SUPPLIERS LISTS

⑤ ALLOCATE INDIRECTS BACK TO THE WORK STATIONS

COST ACCOUNT CATALOG PRICES

② (NEXT) COMPANY ANNUAL PRODUCTION

ENDOGENOUS DEMANDS FROM OTHER COMPANIES

KEY.

QUANTITY

PRICE

SUPPLIER

STANDARDIZED DATA

CALCULATION

COMPANY DATA (INPUT OR CALCULATED)

WORK STATION (PROCESS) DATA (INPUT OR CALCULATED)

Figure 1. The SAMICS Methodology. (1) and (2) Company annual production is that needed within the industry. (3) Direct requirements come from following the company production through the production sequence, using the specified yield factors and accumulating within the firm. (4) Indirect requirements are specified as functions of the totals, which are not known until after the indirects have been found. (5) Indirect requirements are allocated back to the work stations by using the firm's final indirect requirements matrix. (6) Capital expenses are based on capital cost estimating relationships in the standardized Cost Account Catalog, combined with various submodels. Operating expenses require total requirements for and inflated prices (at those quantities) of personnel, utilities, by-products, and commodities. Other price-independent expenses are also calculated. (7)Total expenses include those which depend on total revenue. (8) By allocating the overhead to work stations, the price of every product, including (9) the product of interest, is obtained.

tions must start at the raw materials end of the industry. Expenses also depend on the scale of operation. The scales of operation, on the other hand, are chosen to be just sufficient to manufacture the specified amount of the industry's final product. That is, quantity calculations must start at the finished goods end of the industry. Since prices depend on quantities, but quantities do not depend on price (demand is assumed), the quantity calculations must be performed first. The resultant sequence of calculations is as follows:

(1) The firms in the hypothetical industry are placed in a sequence which is ordered so that every firm appears on the list before any of its suppliers. Work stations in each firm are similarly ordered.

(2) The industry size is an input. Every firm that makes the final product of the industry is assigned an annual production quantity based on its (input) market share.

(3) All quantities, of everything throughout the entire industry, which are implied by the specified industry size are calculated by proceeding sequentially through the ordered sequence of firms, starting at the finished goods end and continuing to the raw materials end. That is, the final output quantities are taken as given, and the quantities that must be produced at each preceding step, taking yield losses into account, are determined sequentially. Some readers may prefer to think of the quantity calculations as proceeding backwards through the industry.

(4) As each firm is addressed in turn, its direct requirements are calculated by sequencing through the ordered list of work stations in much the same fashion. When all of a firm's direct requirements have been accumulated, the implied indirect requirements are inferred. (The algorithms for making these inferences are perhaps *the* major contribution of the SAMICS methodology to the state of the art of economic analysis of manufacturing.) The indirect requirements of the firm are then allocated back to the work stations. Quantities of any required products that are not manufactured within the firm are added to the annual production quantities of the firm's suppliers.

(5) After all quantities have been calculated, it is possible to estimate product prices by dividing each firm's total annualized expenditures by its annual production. (The actual algorithm is somewhat more complicated, so as to allow each firm to produce more than one kind of product.) The determination of a firm's total annualized expenditures incorporates capital cost estimating relationships and financial submodels for capital replacement, depreciation, corporate income taxes, insurance premiums, investment tax credits, property taxes, working capital, interest on debt, return on equity, miscellaneous expenses, and an amortization of one-time costs such as interest during construction, start-up costs and revenues, and depreciation to steady-state. The effects of inflation are included in all of these calculations. Eventually, all expenses are allocated back to the work stations.

(6) Since one component of a firm's expenses is the cost of products purchased elsewhere in the industry, product prices are calculated by sequencing through the ordered list of firms from the raw materials end toward the finished goods end, so that product prices will be available when needed.

(7) Finally, each firm's profit and markup can be calculated.

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Section II

The Environment of the Hypothetical Industry

A. AVAILABLE PROCESSES

The SAMICS procedure was initially developed to provide a means for comparing manufacturing processes. Consequently, a fundamental part of the data environment is a collection of process descriptions.

A *process*, in SAMICS terminology, describes the basic complement of resources that must be replicated to increase production capacity. The process may describe a machine, a "stoichiometric" collection of apparatus, or simply the facilities required to perform a specified function. The SAMICS procedure will generate *work stations* containing enough "machines" — copies of the template provided by the process description — to produce the required amount of product.

A process description has six parts (see References 10 and 11), in addition to a unique identification:

Part 1 — Output Product Description. In order to assign prices to products, it was necessary to require that each process produce one and only one product. If a real process being modeled produces more than one product, two or more SAMICS process descriptions that conform to this requirement must be prepared. It should be noted, however, that a *product*, in the SAMICS context, is an object that must be priced within the model; any "product" that can be assigned a price exogenously should be considered either a *by-product* (if output by the process) or a *commodity* (if input to the process). Since quantities of the output product will be calculated, it is also necessary to specify the units in which these quantities are expressed.

Part 2 — Process Characteristics. Three parameters suffice to describe the economically important operating characteristics of the process: (a) The average rate of production when the process is operating. (b) The average time that goods spend being processed. This information is used only for calculation of in-process inventory. (c) The duty-cycle fraction if at full production. This parameter includes consideration of reliability, maintainability, warm-up and cool-down, and so on.

Part 3 — Equipment Cost Factors. To permit consideration of inflation, depreciation, and the use of separate books for in-house accounting and for taxes, cost data must include not only the purchase price and the anticipated useful life of the equipment, but also the year for which the purchase price is valid, an inflation rate table, the salvage value, and the cost of removing a worn-out piece and installing its replacement. Furthermore, the book and tax depreciation methods must be specified.

Part 4 — Direct Facilities and Personnel Requirements. Facilities are specified as the amount needed per "machine." Personnel is given in terms of the amount needed per "machine" per shift.

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Part 5 — Direct By-Products, Utilities, and Commodities Requirements. Data specified is the rate at which by-products are produced or utilities or commodities are used by each copy of the process.

Part 6 — Input Product Requirements. This data specifies how much of each product which is produced elsewhere in the modeled industry is required for each unit of this process's product.

B. COST ACCOUNT CATALOG

The cost account catalog serves two purposes. First, it provides standard prices for all of the *expense items* that are obtained from outside the modeled industry. Second, it provides standard relationships between direct requirements and the indirect requirements that they imply. In both cases, nonlinear relationships are allowed. Inflation rate tables are associated with each expense item. .

The cost account catalog is divided into six accounts:

Account A — Facilities Parameters. The price versus quantity relationships associated with expense items in this account express initial capital cost estimating relationships, and are not used in the calculation of annual operating expenses. They do, of course, influence the annual capital expenses and, consequently, the total annual expenses. ·

Account B — Personnel. Prices of expense items in this account are intended to include all benefits and "expense accounts," in addition to salaries.

Account C — Utilities and Plant Services. Most of the expense items in this account have indirect requirements for facilities (for example, *domestic water* requires *water service facilities*).

Account D — By-Products. By-products are sometimes produced by a process in addition to the *products* that define the structure of the industry. The category of *by-products* includes saleable items, such as *rejected silicon wafers*; recycleable scrap, such as *reusable polysilicon*; and effluents, such as *poisonous fumes*. The hypothetical industry does not produce pollutants. Potential pollutants, such as *poisonous fumes*, have direct requirements for processing facilities. Some of the processing facilities may reclaim a portion of the by-product — these facilities would have negative indirect requirements for the associated commodities (in Account E). For convenience, since there seem to be more potential pollutants than revenue-producing by-products, it was decided to associate positive prices with those by-products that result in expenses and negative prices with those that produce revenues.

Account E — Commodities. These expense items are simply the materials and supplies obtained from outside the modeled industry.

Account F — Resources. The procedures developed for calculating indirect requirements provide an opportunity to keep track of the requirement for natural resources, such as

energy and *silicon*. Expense items in this account are never required directly and have no prices. These "priceless" expense items are inherent in (that is, indirectly required by) "priced" expense items — for example, each cubic foot of *natural gas* requires 0.302 kilowatt-hours of the resource *energy*. These tabulations may be of particular interest if either the worldwide or the U.S. stock of particular resources is small.

C. AVAILABLE COMPANIES

The data environment contains a collection of company* descriptions to facilitate comparison of the effect of changes in the industry structure on the price of the industry's product.

Company descriptions contain a list of the products made, a list of the processes used, and a list of the suppliers (other modeled companies) for each product purchased from within the modeled industry. Each suppliers list also contains a specification of the percent of the annual requirement purchased from each supplier. In addition to these lists, each company description also specifies values for the financial parameters to be used for that company.

D. STANDARD DATA

The SAMICS methodology is extremely flexible, and should be able to provide reasonably good price estimates when used in a descriptive mode with real company data. For the purpose of comparing manufacturing processes, however, the price estimates produced should be normative, and based on realistic, but standardized data, so that it is indeed alternative processes which are compared, rather than alternative economic assumptions. Hence, standardized values are provided for some of the equipment cost factors, for all expense item prices and indirect requirement relationships, for all inflation rates, and for all of the company financial parameters. Standard values are also provided for the number of working minutes in a year, income tax rates, investment tax credit parameters, depreciation methods, and a few other parameters.

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*In the SAMIS III computer program (References 7, 9) *companies* are associated with the data which is saved from one computation to the next, and *firms* are used to identify the calculated results. Since *companies* and *firms* have a one-to-one correspondence, the two terms are used almost interchangeably throughout this document.

Section III

Structuring the Hypothetical Industry

The user defines the industry by specifying its final product and listing the companies that make that product, with their market shares. Since each company description includes a suppliers list for each product the company buys, the rest of the companies in the industry are identified through the sequence of suppliers lists. These relationships are suggested by Figure 2.

SAMICS then creates firms to correspond to those companies and builds an industry structure — an ordered list — that has the characteristic that all of a company's suppliers appear after it on the list. This structure carries with it the implication (or assumption, if you like) that there are no technological loops in the industry (that is, that no company buys from a company that buys, even indirectly, from it).

Bruce L. Kleine developed an ingenious recursive algorithm for constructing the industry structure. This algorithm, illustrated in Figure 3, builds the structure so that its defining characteristics are satisfied, and readily detects when the structure cannot be built to specifications.

A similar procedure is used within each firm to place work stations into a structured production area, in which supplying work stations always appear after the supplied work stations.
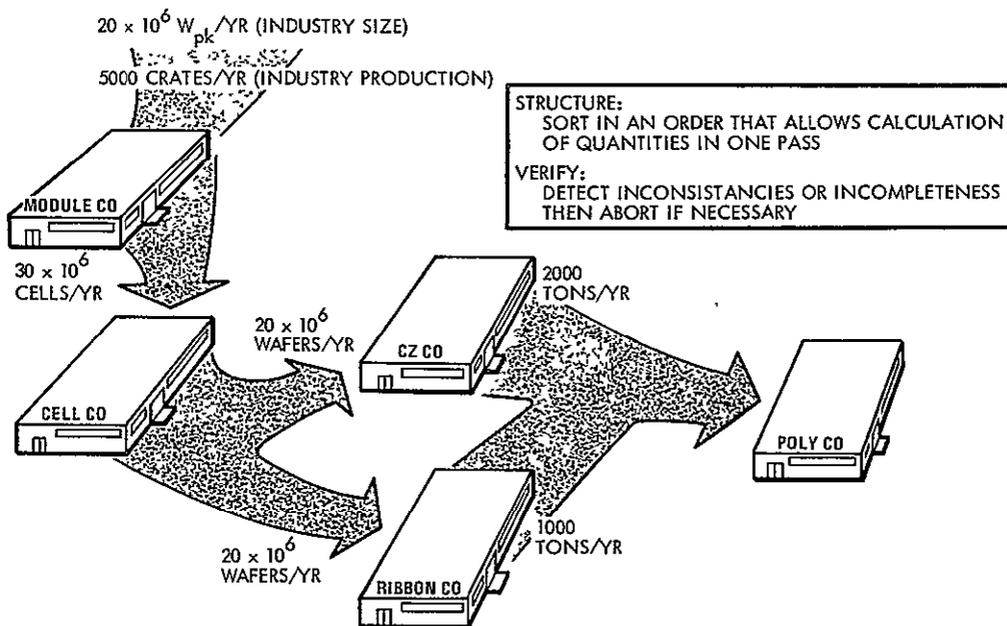
Figure 2. Structuring the SAMICS Industry. The user provides a makers list, which identifies the companies at the finished goods end of the industry. He also provides suppliers lists which identify the next companies in the sequence, until eventually the raw materials end of the industry is reached. Companies are sized so that their capacities match the production quantities implied by the structure of the industry and the industry size specified by the SAMICS user.

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Put all firms that make the industry's product into a pool.
Loop for each firm (still) in the pool:
   Remove the firm from the pool and
   Place it first in the industry structure.
   Place that firm's suppliers in the industry structure*.
Repeat for the next firm in the pool until the pool is empty.
Done.

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*This is the recursive step:

Loop for each supplier of the firm:
   If the supplier is already in the industry structure.
      And if after the supplied firm, its location is OK, so
         Cycle to the next supplier;
      Else if before the supplied firm,
         There is a technological loop: ABORT.
   Else the supplier is not already in the industry structure, so
      If the supplier is in the pool,
         Remove it from the pool.
      Place the supplier in the industry structure immediately after
         the supplied firm. Then,
      Place the supplier's suppliers in the industry structure*
Repeat for the next supplier of the firm (if any).
Return to the previous level of recursion.

Figure 3.   Recursive Algorithm to Structure an Industry

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Section IV

Calculation of Quantities

Product prices are calculated by requiring company revenues to be equal to company expenses. Expenses include the cost of products obtained from other firms in the industry and depend, to some extent, on the scale of operation. Consequently, price calculations must first be performed for those firms at the raw materials end of the industry structure. However, before those price calculations can be made, factory sizes must be determined. The SAMICS procedure therefore starts at the finished goods end, makes a pass through the industry during which all quantities are calculated, then makes another pass from the raw materials end during which all prices are calculated.

The calculation of product quantities requires sequencing through each firm's structured process sequence (that is, through the *work stations* in the firm's *production area*). As each work station is encountered, the number of machines needed to produce that work station's annual production quantity is calculated and the firm's direct requirements are accumulated.

After all of a firm's direct requirements have been accumulated, the indirect requirements relationships are used to generate the firm's total requirements. To take proper account of the firm's economies of scale, the firm's final *indirect requirements matrix* is used to allocate indirect requirements back to the work stations.

The quantity calculations that are made for each company are illustrated in Figure 4.
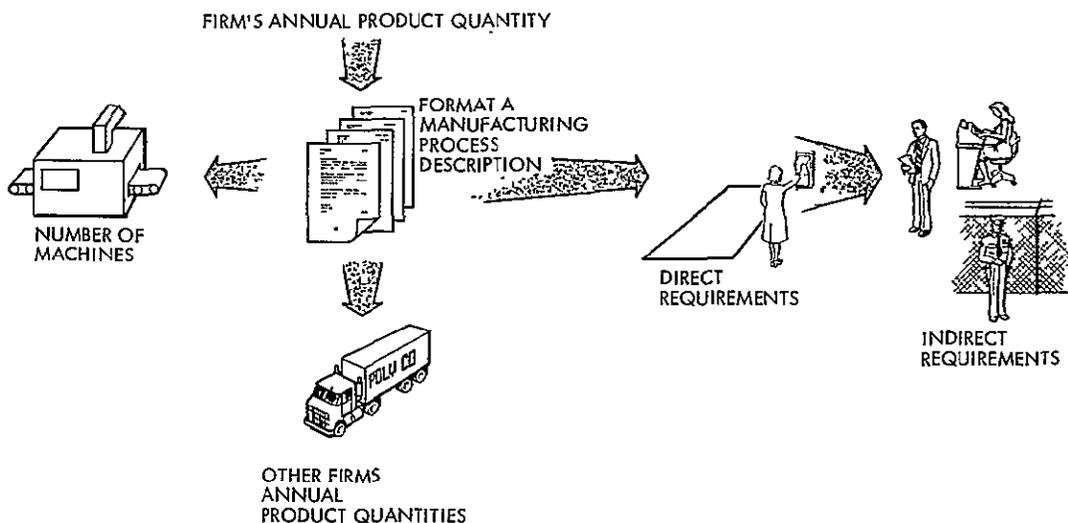
Figure 4. Calculation of Quantities within a Firm. Descriptions of the manufacturing processes used by the firm provide the information needed to calculate the numbers of machines, the direct requirements, and the amounts of required products that the firm needs to manufacture the necessary quantity of the firm's product. Suppliers' lists are used to determine quantities of the products to be manufactured by other firms in the industry. The firm's indirect requirements are inferred from the direct requirements. The resultant indirect requirements are completely allocated back to the processes.

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A. PRODUCT QUANTITIES

The first step in calculating annual product quantities is to convert the industry's size, stated in terms of its objective,* into a product quantity.

$$\text{Annual quantity of the final product of the industry} = \text{(industry size)/(hardware performance)}$$

Example:

Industry objective: New photovoltaic power production capability
Expressed in: Peak-watts per year

Industry size: 15×10^6 peak-watts per year

Final industry product: Solar modules (of a particular design)
Hardware performance: 140 peak-watts per module

Thus, product quantity $= 15 \times 10^6 /140 = 1.0714 \times 10^5$ modules/year.

The industry production is then assigned to each of the firms that make the industry's final product according to their market shares.

$$\text{Annual quantity of the final product allocated to a firm that makes it} = \left(\begin{array}{c}\text{annual quantity of}\\ \text{the final product}\end{array}\right) * \text{(firm's market share)}$$

Since each company may make more than one product, this quantity is inserted into the appropriate element of a product quantities vector, which could** already contain entries from exogenous demands (from outside the modeled industry).

Having thus gotten the final product production into the industry structure, it is now straightforward to determine the production quantities of all other firms in the industry structure. Each firm is considered in the order in which it occurs in the structure. As a firm is encountered, its structured process sequence is followed, from the finished goods end toward the raw materials end. Process yields are used to determine the annual amount of each required product needed. If the required product is manufactured by another process in that company, the product quantity of that process is increased by the required product annual amount. If the required product is not manufactured within the firm, the firm's procurement requirements are increased. After all of the procurement requirements have been determined, the company's suppliers list is used to augment the production quantities of the supplying firms according to the fraction of the procurement that each supplies.

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*The term *industry objective* may be somewhat awkward when SAMICS is applied outside the context of the Low-Cost Solar Array Project. The basic idea is that the final product *does* something, and that the industry objective is expressed in terms of the amount of that something. It may be more convenient to equate the industry objective to the industry's final product. Then, the industry size and the industry's final product would be expressed in the same units, and the *hardware performance* would be unity.
**Incorporation of exogenous demand is not implemented in the SAMIS III computer program.

B. NUMBER OF MACHINES

As each work station is encountered while proceeding through the firm's production area, a number of simple calculations are made. The relevant equations follow:

$$R = Q/T$$

where

R = required number of machine operating minutes

Q = annual quantity produced at this work station

T = output rate of one machine, in units per minute.

$$A = F * P * NS * H * m * (D * W - E)$$

where

A = actual number of minutes that one machine operates in a year

F = process usage fraction, the fraction of the time that the plant is operating that a particular machine would operate if at full capacity (considering reliability/maintainability, cleaning, set-up, warm-up/cool-down, etc.)

P = fraction of capacity at which plant is operating

NS = number of shifts the company operates per fiscal day (normally 1, 2, or 3)

H = number of fiscal hours the company operates during each shift (typically 8)

m = number of minutes the company operates in each fiscal hour (60)

D = number of fiscal days the company operates per fiscal week (normally 5 or 7)

W = number of fiscal weeks the company operates per fiscal year (normally 52)

E = number of plant holidays per fiscal year (may be none; the term $(D * W - E)$ is the number of days the plant is open during the fiscal year)

$$N = R/A$$

where N = actual number of machines needed to produce Q.

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Since it is usually impossible to purchase a fraction of a machine, N is normally* rounded up to the next larger integer.

$$M = R / [NS * H * m * (D * W - E)]$$

where M = ideal number of machines required if there were no downtime and no extra capacity.

$$I = N - M$$

where I = number of idle machines.

C. DIRECT REQUIREMENTS

The direct requirements of each work station are obtained by multiplying the one-machine direct requirements that are part of the input process description by a multiplier that depends upon the cost account of the relevant expense item:

If the account is "A" (facilities parameters), then

$$q = r * N$$

where

q = amount of this facility parameter needed

r = amount of this facility required per machine (input)

N = number of machines (after rounding to an integer).

If the account is "B" (personnel), then

$$q = r * n * S$$

where

q = annual number of personnel (of this type) needed

r = number of positions required per machine (input)

n = number of machines (before rounding to an integer)

S = shift multiplier,** in persons (required) per position

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*If the fraction is less than $\epsilon * N$, where ϵ is an input, N is rounded down instead of up. Alternatively, non-integer numbers of machines may be allowed — if this option is used, results must be interpreted with care, because it implies the assumption that machine prices are linear with output rate.
**In Release 1 of the SAMIS III computer program (References 7 and 9), the shift multiplier was fixed at a value of 4.7, corresponding to the following assumptions:

NS = 3 shifts	h = 8 hours/shift
H = 8 hours/shift	d = 5 days/week
D = 7 days/week	w = 52-1/7 weeks/year
W = 52-1/7 weeks/year	e = 8 days/year
E = 20 days/year	v = 13.5 days/year
	a = 19.0 days/year

Later releases, in which S will not be fixed at 4.7, will take into account the fact that the indirect requirement relationships also depend upon the number of shifts.

The shift multiplier, S, is not simply the number of shifts; it must include consideration of holidays, vacations, sick leave, and absenteeism. It can be calculated by equating the number of hours that the company operates during a year to the product of S and the number of working hours produced by a person working one shift.

$$S = [NS * H * (D * W - E)] / [h * (d * w - e - v - a)]$$

where

NS = number of shifts

H = number of fiscal hours per shift

D = number of fiscal days per fiscal week

W = number of fiscal weeks per fiscal year

E = number of plant holidays per fiscal year

h = number of working hours per person for shift (normally, $h = H$, and both factors can be omitted)

d = number of working days per working week for personnel (normally 5, perhaps 4 or 6)

w = number of working weeks per fiscal year for personnel (normally 52)

e = number of paid holidays per fiscal year (typically 6 to 10; if $E > 0$, e may equal E)

v = average number of paid vacation days (typically 10 to 15) per fiscal year

a = average number of paid absenteeism days per fiscal year (sick leave, illness in family, etc.; the term $(d * w - e - v - a)$ is the number of days the average worker comes to work during the fiscal year).

If the account is "C" (utilities and plant services), "D" (by-products), or "E" (commodities), then

$$q = r * R$$

where

q = amount of this utility or commodity required or of this by-product produced per year

r = amount required (or produced) per machine per minute (input)

R = required number of machine operating minutes.

Direct requirements for the firm are obtained by simply accumulating those of the work stations within the firm. (The purpose of the accumulation is to take advantage of any economies of scale that result from the firm's larger purchasing power).

D. TOTAL REQUIREMENTS OF THE FIRM

Operation of a company requires more facilities, more staff, more utilities, and more supplies than merely the direct requirements. A great deal of attention, typified by References 12-25, has been given to the problem of estimating what these additional requirements cost. The approach usually taken is to determine overhead factors by which the costs of the direct requirements can be multiplied to obtain total costs. This approach can be quite satisfactory when applied within an existing company or when applied to a well-established industry. In fact, the manual implementation of the SAMICS methodology, IPEG (Reference 2), uses it. However, determination of those overhead factors requires the introduction of a variety of assumptions, some of which are questionable when applied to an industry which does not have a historical data base. In particular, the IPEG model distinguishes five kinds of direct requirements: equipment costs, floor space, personnel, utilities, and commodities (materials and supplies); few other models are as explicit as IPEG, so that comparisons between highly automated process sequences and mostly manual process sequences resulting from such models would be unreliable. It should be pointed out that few, if any, of those models are applied to such a wide range of technological possibilities as SAMICS/IPEG must be.

To permit application to extremely wide ranges of possible industry and company sizes and of technological content, the SAMICS methodology makes an explicit determination of indirect requirements. A major portion of the SAMICS model of the hypothetical factory is embodied in indirect requirements relationships (see Reference 5, Volume II), which are of the following form;

$$IND_i = \Sigma_j f_{ij} (TOT_j)$$

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where

IND_i = indirect requirement for expense item i

TOT_j = total requirement for expense item j

$f_{ij}(\ )$ = functional relationship represented for computational convenience as a piece-wise power function (Note: Power = 1 implies "linear"). (See References 26 and 27.)

The above equation expresses the description of indirect requirements used by SAMICS, but it is so mathematically succinct that it is somewhat obscure. The equation says that the indirect requirement for expense item i is given by the sum of the indirect requirements for item i that result from the total amounts of every expense item (denoted j). For example, consider the indirect requirement for *passages and corridors*. Only three expense items have "first-level" indirect requirements for *passages and corridors*: *administrative office space, plant manufacturing office space,* and *total manufacturing floor space*. If we label these expense items 1, 2, 3, 4, respectively, we have

$$\text{i or j} = 1 — \textit{Passages and corridors}$$

$$\text{i or j} = 2 — \textit{Administrative office space}$$

$$\text{i or j} = 3 — \textit{Plant manufacturing office space}$$

$$\text{i or j} = 4 — \textit{Total manufacturing floor space}$$

$$f_{12}(\text{TOT}_2) = 1/20 * \text{TOT}_2$$

$$f_{13}(\text{TOT}_3) = 1/15 * \text{TOT}_3$$

$$f_{14}(\text{TOT}_4) = 1/10 * \text{TOT}_4$$

That is, 1.0 square foot of *passages and corridors* is required for every 20 square feet of *administrative office* space, and so on. Then, the first-level indirect requirement for *passages and corridors* would be given by

$$\text{IND}_1 = 1/20 * \text{TOT}_2 + 1/15 * \text{TOT}_3 + 1/10 * \text{TOT}_4$$

Use of this formulation assumes that there is little interaction (other than additively) between indirect requirements. Or, to put it another way, possible synergism among total requirements, with regard to indirect requirements, is negligible.

The form of $f_{ij}(TOT_j)$ can be considerably more general than was shown in the above example: A piece-wise power function has the general form:

$$f_{ij}(TOT_j) = \begin{cases} r_{ij1} * (TOT_j - S_{ij1})^p & \text{for } 0 \leq TOT_j < a_1 \\ r_{ij2} * (TOT_j - S_{ij2})^p & \text{for } a_1 \leq TOT_j < a_2 \\ \quad \cdots \\ r_{ijk} * (TOT_j - S_{ijk})^p & \text{for } a_k \leq TOT_j \end{cases}$$

The fact that only first-level indirect requirements relationships need to be stated is a consequence of using total requirements as the independent variable. Second-level indirects are obtained by finding the first-level indirects of the first-level indirects portion of the total requirements; third-level indirects come from the first-level indirects of the second-level indirects portion of the total; and so on. To illustrate this point, consider the above example again. *Administrative office space* (one of the determinants of *passages and corridors*) is a first-level indirect requirement of *total staff personnel*, which is a first-level requirement of (52 kinds of staff personnel, including) *assembly foreman*, which is a first-level requirement of (7 kinds of direct personnel, including) *general assembler*. Thus, *passages and corridors* is a fourth-level indirect requirement of a *general assembler*, and a change in the direct requirement for a *general assembler* will indeed cause a change in the requirement for *passages and corridors*.

Since the indirect requirements relationships are based on total requirements, and since only direct requirements have been calculated so far, some kind of an algorithm is needed to deduce the total requirements.

Suppose the total requirements of the firm were known. That is, suppose the annual amount (or, in the case of facilities, simply the amount) of each expense item were known. (For convenience, some expense items are composites, such as *office supplies*.) There may be a couple of hundred different items; the corresponding amounts can be put into a vector, which can be denoted TOT. Then, the vector of annual indirect requirements, denoted IND, is given by

$$IND = R * TOT$$

where R = the *indirect requirements matrix* (which is really a matrix of functional operators, but which is an ordinary matrix of numbers if those functions are as simple as in the example just given — that is, simple multiples with no constant term).

By defining a similar vector of direct requirements, DIR, another expression for TOT can be written:

$$TOT = DIR + IND$$

The total, and simultaneously the indirect, requirements can be determined by solving these two (potentially nonlinear) sets of equations. If the R matrix contains constants, the solution* is

$$TOT = (I - R)^{-1} * DIR$$

where I is the identity matrix.

Economists will recognize this result as similar to that obtained by Leontief (References 28-32) in his studies of input-output matrices. There are, however, several significant differences. In input-output analysis, the adjustments result in an equilibrium solution set in a dynamic economic system, which has led to some criticism of the applicability of the results. In SAMICS, all of the indirect requirements adjustments take place during the designing of the factory, which is not a dynamic situation. Furthermore, as actually applied in the SAMIS III computer program, the indirect requirements matrix contains not constants, but piece-wise power functions, which can provide a much more powerful description of the relationships.

Two algorithms (see Figure 5) have been developed to solve the two sets of equations. The algorithms themselves are explicitly presented in Reference 7, pages 70 and 71; theoretical analyses of these algorithms will be presented in forthcoming papers. Briefly:

- The "fast" algorithm sets the first guess of the total requirements equal to the direct requirements, then finds the indirects associated with each element of the total requirements vector. Each time an indirect requirement is changed (initially, they are all zero), the associated total requirement is changed. This procedure is continued over and over until the change in every indirect requirement is less than epsilon (an input quantity) of the total requirement. There are some pathological indirect requirements relationships known that can cause this procedure to fail to converge.

- The "slow" algorithm fills the indirect requirements matrix with the linearized slopes of the piece-wise power functions, then solves the Leontief equation (suitably modified to account for the constant terms of the linearizations) by inverting the matrix. A recursive partitioning scheme is employed to take advantage of the fact that many of the elements in the indirect requirements matrix are identically zero,

*An alternative derivation of this result can be obtained by noting that R * DIR generates indirect requirements. These indirects lead to additional indirects: R * (R * DIR), and this process may be repeated until the additional indirects generated are negligibly small. This procedure leads to the following equation:

$$IND = R * DIR + R^2 * DIR + R^3 * DIR + . . .$$

$$= (R + R^2 + R^3 + . . .) * DIR$$

So that

$$TOT = DIR + IND = (I + R + R^2 + R^3 + . . .) * DIR$$

If the sum in parentheses converges, it converges to the expression given in the body of the text.·

Both derivations lead to an implementation problem. The R matrix is defined in terms of the total requirements, not the direct requirements. Hence, the computational algorithm must allow the R matrix to be adjusted from the best original basis, namely DIR, to the correct basis, TOT.
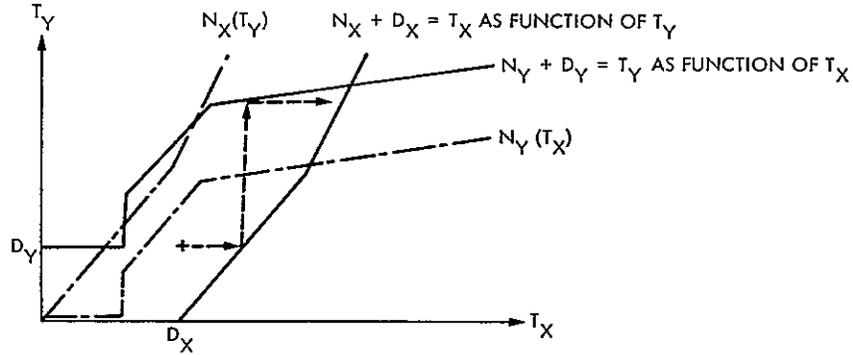
Figure 5. Two Algorithms for the Economy of Scale (Indirect Requirement) Calculation. The "fast" algorithm finds successively better estimates of the indirect requirements vector one component at a time. The "slow" algorithm uses a piece-wise linearization of the indirect requirements relationships, then improves the entire indirect requirements vector all at once by solving the Leontief equation. Additional matrix inversions are needed until the solution is within the current piece of every piece-wise linear function.

thereby reducing* the size of the matrix to be inverted. This algorithm is not subject to the pathologies that could afflict the "fast" method, but there can be problems in changing pieces at the breakpoints of the piece-wise continuous functions when solutions are beyond those breakpoints. Pathological indirect requirements relationships that can cause this algorithm to fail to converge are also known.

Both algorithms need further attention on the theoretical level, but no difficulties have been experienced** as of yet in actual applications.

E. ALLOCATION OF INDIRECT REQUIREMENTS TO WORK STATIONS

Once the indirect requirements of the firm have been determined, they are allocated back to the work stations for the subsequent process-by-process price determinations. Calculation of indirect costs, however, must have taken place at the company level in order to properly account for economies of scale.

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*In a recent application, the initial matrix had a rank of 165; six partitions reduced the rank to 48, thereby saving over 95% of the computational effort.

**The current SAMICS standardized indirect requirements relationships data base does not contain any functions that are "pathologic" to the "fast" algorithm.

In the previous section, the-Leontief equation,.

$$TOT = (I - R)^{-1} * DIR$$

was not applied explicitly. (The indirect requirements matrix, R, was identified as a matrix of functional operators. The "fast" algorithm solves the two sets of equations from which the Leontief equation was derived, rather than the equation itself, and the "slow" algorithm solves a modification of the Leontief equation that accounts for the constants that come about when the functions are linearized.) It can be applied explicitly to the allocation of indirect requirements in the form

$$TOT_i = (I - R)^{-1} * DIR_i$$

where

TOT_i = total requirements of work station i

DIR_i = direct requirements of work station i

by defining the elements of R appropriately. That is,

R_{ij} = the amount of expense item i required indirectly by the firm per unit of the total requirement of the firm for expense item j.

Then, since the Leontief equation is linear, summation of the work stations' total requirements will equal the firm's total requirements. (Thus, all of the indirect requirements will have been allocated.)

This is not the only allocation scheme possible. It might be desirable, for example, to assign to each work station the *marginal* (or *change in*) indirect requirements that would result from putting this work station into the firm, rather than the *average*, which this procedure assigns. If that were done,* the work stations' indirect requirements would not sum to the firm's (nor, of course, would the total requirements).

The algorithm currently implemented in the SAMIS III computer program, after constructing the indirect requirements matrix as defined above, uses the recursive partitioning algorithm to invert the matrix once for the firm, then applies the Leontief equation to each work station.

The recursive partitioning algorithm was not available for the first release of the program (References 7 and 9), so an alternative algorithm was used.

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*Implementation would be easy — simply use the same slopes as required by the "slow" algorithm as the values for the R_{ij}.

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$$IND_i = R * TOT_i$$

$$TOT_i = DIR_i + IND_i$$

Substitute the second equation into the first, to get

$$IND_i = R * (DIR_i + IND_i)$$

Repeated substitution gives the algorithm shown in Figure 6, which assumes that R already contains the appropriate indirect requirements matrix.

Loop for each work station in the firm
    Let DIR = the work station's direct requirements vector
    Let IND_{ONE} = R * DIR
    Initialize IND_{OLD} to IND_{ONE}
    Initialize IND_{NEW} to R * IND_{ONE} + IND_{ONE}
    Loop until no element of the IND vector changes
        Put IND_{NEW} into IND_{OLD}
        Let IND_{NEW} = R * IND_{OLD} + IND_{ONE}
    Repeat for another iteration
Repeat for the next work station

Figure 6. SAMIS III Release 1 Algorithm for Allocation of Indirect
Requirements to Work Stations .

F. SUMMARY OF QUANTITY CALCULATION EQUATIONS

The equations presented in this section are not identical to those of the preceding sections. Some of those equations were expressed in narrative, but not expressed explicitly. Others were given in slightly different forms than appear here.

1. Product Quantities

$$IQ = IS / HP$$

where

    IQ = annual quantity of the final product of the industry

    IS = industry size

    HP = hardware performance.

$$FQ = IQ * MS$$

where

FQ = annual quantity of the industry's final product made by a particular firm

MS = that firm's market share.

$$Q_i = FQ$$

where

Q_i = annual quantity of product manufactured by process i, when i is the last process in the company's manufacturing process sequence.

$$Q_i = \Sigma_j \, Q_j \, / \, (Y_{ji} * IR_{ji})$$

where

Q_i = annual quantity of product manufactured by process i, when i is not the last process in the company's manufacturing process sequence

Σ_j = summation over all processes j that follow process i in the company's manufacturing process sequence

Y_{ji} = manufacturing yield of process j with respect to the product of process i

IR_{ji} = ideal ratio (units out per unit in with no yield loss) of the product of process j to the product of process i.

$$PQ_i = \Sigma_j \, Q_j \, / \, (Y_{ji} * IR_{ji})$$

where

PQ_i = annual quantity of product i purchased from a supplying company, when i is not manufactured within the company

Σ_j = summation over all processes j in the company.

$$SQ_{ij} = PQ_i * FS_j$$

where

SQ_{ij} = annual quantity of product i obtained from supplier j

FS_j = fraction of the company's need for product i which is obtained from supplier j.

2. Number of Machines

$$R_i = Q_i / T_i$$

where

R_i = number of operating minutes required of process i

Q_i = annual quantity produced by process i

T_i = output rate of one process i machine.

$$A_i = K * P * F_i$$

where

A_i = number of minutes that one process i machine operates in a year

K = number of plant operating minutes in a year (which depends upon the number of shifts and several other plant operating parameters)

P = fraction of capacity at which the plant is operating

F_i = process i machine availability.

$$n_i = R_i / A_i ; \quad N_i = \text{roundup } (n_i)$$

where

n_i = number of process i machines needed (noninteger)

N_i = integer number of process i machines.

$$M_i = R_i / K$$

where

M_i = ideal number of process i machines (no downtime, no unused capacity).

$$I_i = N_i - M_i$$

where I_i = number of idle process i machines.

3. Direct Requirements

Facilities:

$$q = r * N_i$$

where

q = amount of facility parameter required by process i

r = direct requirement per process i machines

Personnel:

$$q = r * n_i * S$$

where

q = annual number of persons required by process i

S = shift multiplier (which depends upon the number of shifts and several other plant operating parameters).

All Others:

$$q = r * R_i$$

where q = annual amount required by process i.

4. Total Requirements

$$IND_i = \Sigma_j f_{ij} (TOT_j)$$

where

IND_i = indirect requirement for expense item i

Σ_j = summation over all expense items j needed by the company

f_{ij} = indirect requirement relationship of expense item j for expense item i

TOT_j = total requirement of the company for expense item j.

$$f_{ij}(TOT_j) = r_{jik} * (TOT_j - S_{ijk})^p \qquad \text{for } a_{k-1} \leq TOT_j < a_k$$

where

$$\left. \begin{array}{l} r_{ijk} \\ \text{and} \\ S_{ijk} \end{array} \right\} = \text{coefficients of the piece-wise power function}$$

a_k = breakpoints of the piece-wise function

p = exponent of the piece-wise power function.

$$IND = R * TOT$$

where

IND = vector representation of the indirect requirements of a firm

R = indirect requirements matrix of the firm

TOT = vector representation of the total requirements of a firm.

$$TOT = DIR + IND$$

where DIR = vector representation of the direct requirements of a firm.

$$TOT = (I - R)^{-1} * DIR$$

where I = the identity matrix.

5. Allocated Indirect Requirements

$$TOT_i = (I - R)^{-1} * DIR_i$$

where

TOT_i = total requirements of work station i

DIR_i = direct requirements of work station i.

$$IND_i = TOT_i - DIR_i$$

where IND_i = indirect requirements of work station i.

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Section V

Calculation of Prices

Prices* can be calculated for èach firm in the hypothetical industry by applying the *required revenue condition* (cf. Referencè 1), which states that each company's annual** revenues must be just sufficient to allow the company to meet all of its annual expenses (which include a "reasonable" profit as one of the expenses).

Once product quantities have been determined throughout the hypothetical industry, it is possible to determine the total annual expenses of each company, and hence all product prices, provided the calculation starts at the raw materials end of the industry so that procured product prices are always known when needed. (See Figure 7, which hints at the complexity of the problem, and possibly provides an excuse if the reader finds this section somewhat confusing.)

Total annual expenses of a firm include the following components:

- Procured product expense
- Annual operating expense
- Capital-related expenses
- Price-independent overhead expenses
- Price-dependent overhead expenses

Each of these components will be discussed in detail in the pages which follow.

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*The resultant normative *SAMICS price* is not likely to be the price observed in the marketplace, even though it does include profit as one of the expenses. First, marketing and distribution is outside the scope of the SAMICS price estimate (but see Reference 33). Second, SAMICS assumes steady production with no seasonal (or any other) variations in demand. Third, SAMICS assumes that standardized plants are built, staffed, and operated from scratch; real factories will face special conditions that could increase or decrease some expenses. Fourth, SAMICS assumes a steady, attractive, competitive environment. Real companies may choose to use complicated pricing policies, and/or the marketplace may allow a higher profit than specified by SAMICS. Fifth, although SAMICS provides a very robust price estimate, real processes are likely to have somewhat different characteristics than those supplied as input data, particularly when SAMICS process descriptions are derived from laboratory experiments rather than from in-plant observations. Sixth, if SAMICS is applied to only a few of the products manufactured by a diversified company, the effects on overhead and economies of scale resulting from the other products being made will not have been taken into consideration.

On the other hand, the SAMICS price estimate is based on a very comprehensive, detailed model of the costs of manufacturing, and takes into account economies of scale, the effects of automation on overhead, the peculiarities of the tax laws, and a host of other factors. Extensive validation activities (Reference 4 and several not yet published studies) have shown SAMICS prices to be quite credible, even when some of the underlying assumptions (such as steadiness of production) are violated. *Differences* in price estimates resulting from computations based on *competing* processes can be expected to be highly accurate.

**Annual revenues and expenses are assumed to grow at the rate of inflation, so this condition will be met every year — not just in the standard manufacturing year. Some of the expenses (especially the amortized one-time costs) are *annualized* equivalents of nonsteady cash flows. The annualization procedure used in the SAMICS methodology takes the effects of inflation into account as well as the company's discount rate.
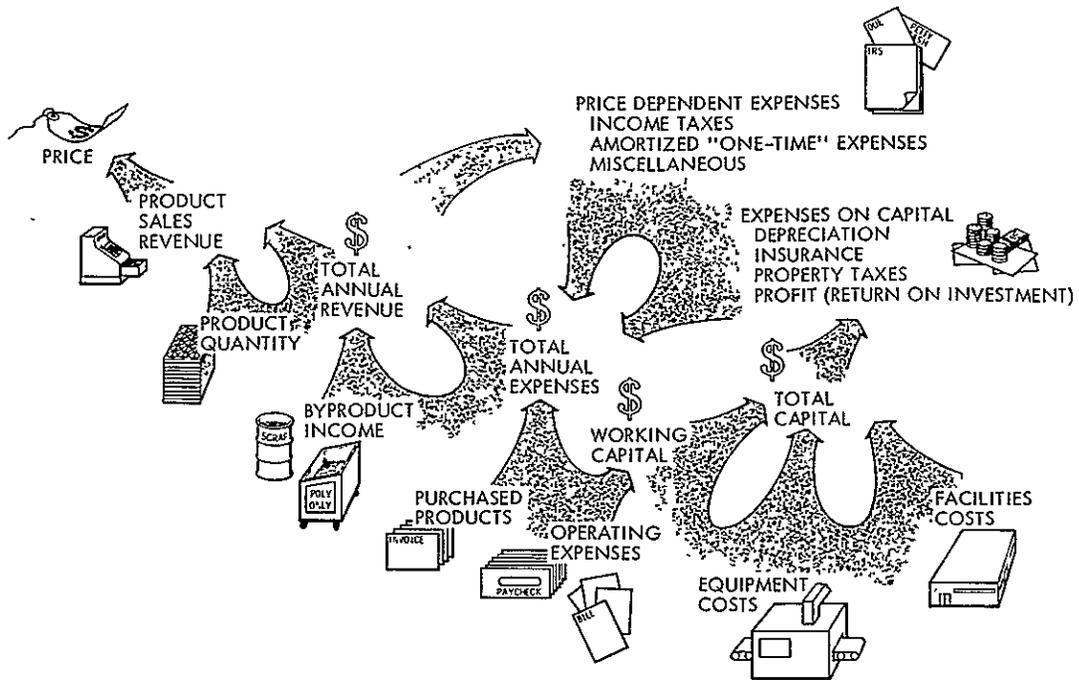
PRICE DEPENDENT EXPENSES
INCOME TAXES
AMORTIZED "ONE-TIME" EXPENSES
MISCELLANEOUS

EXPENSES ON CAPITAL
DEPRECIATION
INSURANCE
PROPERTY TAXES
PROFIT (RETURN ON INVESTMENT)

PRICE

PRODUCT
SALES
REVENUE

TOTAL
ANNUAL
REVENUE

PRODUCT
QUANTITY

TOTAL
ANNUAL
EXPENSES

BYPRODUCT
INCOME

WORKING
CAPITAL

TOTAL
CAPITAL

PURCHASED
PRODUCTS

OPERATING
EXPENSES

FACILITIES
COSTS

EQUIPMENT
COSTS

Figure 7. The Components of the Price Calculation. Inflation and the time value of capital must also be considered. The most important point is illustrated at the upper left: Product prices are determined so that annual revenues just equal the total annual expenses, with profit — resulting from a specified rate of return on equity — treated as one of the annual expenses. Profit margins and markups are computed, not input.

A. PROCURED PRODUCT EXPENSE

The products that the firm procures elsewhere in the modeled industry may be obtained from several suppliers, each of which may have a different price. Rather than try to determine a single price that might (or might not) result from marketplace interactions, a weighted average price is obtained, where the weighting factors are the fractions of this company's need which are supplied by each supplier.

Then, each work station's annual cost of purchased products is augmented by the product of the average price of the procurement and the annual amount needed by the work station.* (This does not include the costs of placing the orders for purchased products, as they result from the indirect requirements associated with the procurement department.)

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*An alternative approach would be to buy entirely from the lowest price supplier. A user of the SAMICS methodology can rerun SAMIS with a revised suppliers list to assess the implication. The SAMIS program cannot use this approach without redoing the quantity calculations for that entire end of the industry. To put it another way: The structure of the industry is implicitly defined when the suppliers' percentages (and market shares of the makers of the final product) are input. All manufacturing capacities are implicitly defined when the industry size is input. A firm cannot buy more from any supplier than was specified as input because that supplier is already operating as close to capacity as he wants to.

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B. ANNUAL OPERATING EXPENSE

The operating expense is the cost of obtaining all of the firm's annual requirements for expense items in accounts B, C, D, and E (that is, personnel, utilities, by-products, and commodities) — except revenue-producing by-products — plus the cost of procured products. Revenue-producing by-products are excluded from this calculation because the annual operating expense is used later in the working capital computation, and it is assumed that by-product revenues do not reduce working capital requirements (Reference 4). The effect of by-product revenues on total annual expenses is treated explicitly later on.

The price of each expense item is obtained by interpolating in the price versus quantity table contained in the standardized cost account catalog, thereby obtaining purchasing economies of scale at the firm's level of operation. This price is then escalated by the inflation rate table applicable to that expense item (which is also supplied by the standardized catalog) to the standard manufacturing year.

Prices are multiplied by quantities and added to the firm's annual operating expense. The calculated prices are also saved for later use at the work station level of computation.

C. CAPITAL RELATED EXPENSES

The term *capital related expenses* is used here to refer only to those expenses that can be readily attributed to the work stations: equipment replacement, facilities replacement, depreciation (the IRS-acceptable model of replacement expenses), and investment tax credit. The remaining expenses that result from the need for capital investment are treated later in this document as overhead: insurance premiums, nonincome (property) taxes, interest on debt, return on equity, one-time costs, income taxes, and, inevitably, miscellaneous expenses. In the course of calculating capital related expenses, it is necessary to determine the initial value and both the accounting and the tax book values of land, facilities, and equipment.
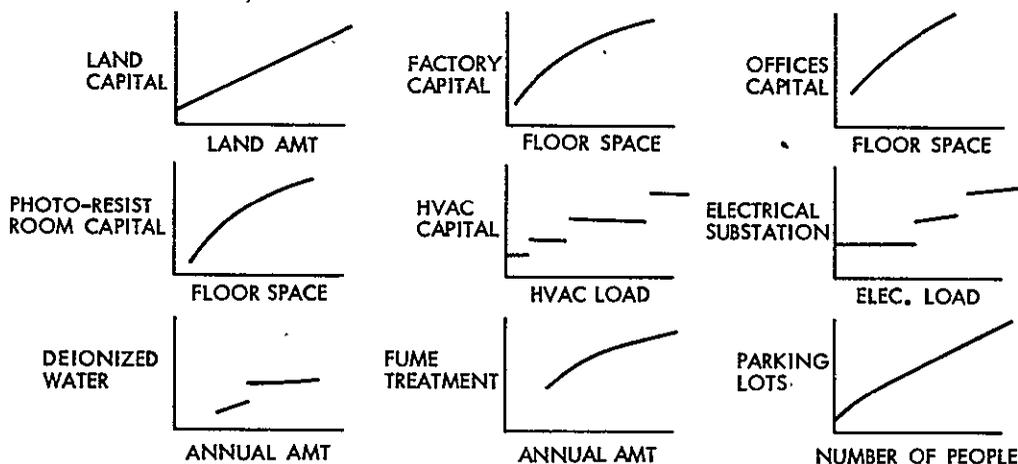

Figure 8.   Illustrative Facilities Capital Cost Estimating Relationships and Indirect Requirements Relationships

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1. Capital Replacement Expenses and Annual Investment

The calculations described in this subsection are performed for each work station in the firm and the resultant expenses and values are accumulated for the firm. Similar calculations are performed for the firm's facilities, except that the "purchase cost" for facilities is obtained by summing costs of the firm's requirements for expense items in account A (see Figure 8), salvage value is assumed to be negligibly small, and the "cost of removal and installation" is assumed to be included in the prices. The "payment float interval" (defined below) is also assumed to be negligible.

First, the cost of replacing each component in the machine description of the process is determined:

$$CINV_{deflated} = C_{deflated} - S_{deflated}$$

where

$CINV_{deflated}$ = investment needed to replace the component, expressed in component price year (an input) dollars

$C_{deflated}$ = purchase cost of a new component (input)

$S_{deflated}$ = salvage value of the replaced component (input).

$$CRPL_{deflated} = CINV_{deflated} + R_{deflated}$$

where

$CRPL_{deflated}$ = cost of replacing the component

$R_{deflated}$ = cost of removing a worn-out component and installing a replacement (input).

The component's escalation rate table (input) is used to express the initial cost, the investment, and the replacement cost in manufacturing year dollars:

$$CINIT = C_{deflated} * \text{(inflation factor)}$$

$$CINV = CINV_{deflated} * \text{(inflation factor)}$$

$$CRPL = CRPL_{deflated} * \text{(inflation factor)}$$

The capital value of the equipment needed to build the work station in the standard manufacturing year is obtained by multiplying the initial cost of the component, CINIT, by the number of machines and summing for all of the components.

The company does not have to replace every machine every year. Consequently, capital replacement expenditures will vary from year to year. This is rather awkward, since an annual expense is desired. The *expected* annual expense, however, can be readily determined by noting that the probability that replacement expenses will occur in any particular year* is the reciprocal of the anticipated useful life. If the plant has many pieces of equipment, not necessarily all the same kind, summation of expected replacement costs should provide a very good estimate of the actual replacement costs. Furthermore, since the objective of determining these costs is to estimate product prices, and those prices are unlikely to vary significantly as a result of stochastic variations in equipment lifetimes, the use of expected lifetimes is further justified.

If the company can receive and install a component before it must be paid for, the *payment float interval* can be used to further reduce the cash outlays required. (The default value of the payment float interval is zero.)

The contribution of the component to annual capital replacement expense and to the investment made in the standard manufacturing year are given by the following equations.

$$f = N / [(1 + k)^V * L]$$

where

f = factor to account for the number of machines, the payment float interval, and the machine lifetime

N = number of machines

k = the firm's average after-tax cost of capital
  = $(1 - \tau) * (\lambda - 1) * i/\lambda + r/\lambda$

v = payment float interval

L = expected useful life

τ = the firm's income tax rate**

λ = the firm's capital leverage = (total capital / equity)

i = the firm's debt interest rate

r = the firm's rate of return on equity.

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*That is, "in any particular year — after the plant has been in operation for several equipment replacement cycles so that it has reached *steady-state* conditions." The impacts of non-steady-state conditions on expenses are discussed in detail in the section on the amortization of one-time costs. The consequences and implications of starting factory operation with all new facilities and equipment are discussed in the subsection on depreciation to steady-state.

**Strictly speaking, the firm's income tax rate will not be known until after the total revenues have been calculated. SAMICS assumes that the largest rate in the income tax rate tables will provide sufficient accuracy for this calculation.

$$RPL = CRPL * f$$

$$INV = CINV * f$$

where

   RPL = contribution to the firm's annual equipment replacement expense

   INV = contribution to the firm's capital investment in the standard manufacturing year.

The annual investment, INV, is calculated in order to determine investment tax credit, book-values, and depreciation, which are discussed in the next three subsections.

$$ITC = INV * itc$$

$$VAL_{book} = INV * book$$

$$VAL_{tax} = INV * tax\ book$$

$$DEP = INV * dep$$

where

    ITC = contribution to investment tax credit

    VAL = contribution to capital valuation of the firm (either accounting book value or tax book value)

    DEP = contribution to annual depreciation (for use in computing income taxes)

$$\left.\begin{array}{l} itc \\ book \\ tax\ book \\ dep \end{array}\right\} = \text{factors whose values will be developed in the next three subsections.}$$

2. Investment Tax Credit

To encourage investment in durable equipment, the government allows a tax credit for equipment investments. No investment tax credit is currently allowed for facilities investments, but the SAMICS methodology provides an option to permit investigation of the price impact of a suitable change in the law.

The SAMICS investment tax credit submodel is shown in Figure 9, and is based on the discussion in Reference 4.

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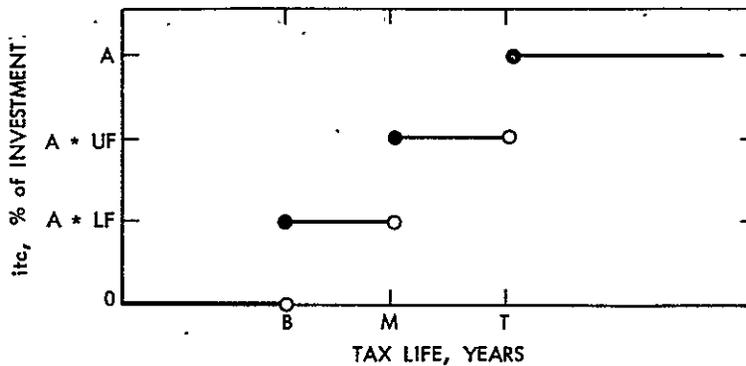
Figure 9. Investment Tax Credit Submodel. The investment tax credit allowed to encourage investment in durable goods depends upon the tax life used in the depreciation of that equipment as shown in this figure. No credit is allowed if the tax life is less than 3 years, 1/3 of the maximum credit is allowed if the life is between 3 and 5 years, 2/3 if between 5 and 7 years, and the full 11% of the credit is allowed if the tax life is 7 years or more. The numerical parameters of this function are standardized inputs to the SAMICS methodology.

A = standard investment tax credit rate (input, default is 11%)

UF = standard upper fraction (input, default is 2/3)

LF = standard lower fraction (input, default is 1/3.)

T = standard upper life (input, default is 7 years)

M = standard middle life (input, default is 5 years)

B = standard bottom life (input, default is 3 years)

Tax Life = standard tax life fraction (input, default = 2/3) * expected useful life

Tax Life is generally rounded up to the next integer, if this calculation does not produce an integer.

The Tax Reform Act of 1976 (see Reference 4) limits investment tax credit to 50% of the current year's federal income tax liability, but unused credits can be carried forward 7 years or back 3 years. The hypothetical SAMICS company operates in a steady-state, so no carry-forward or carry-back need be considered. The investment tax credit is limited to a standard maximum percentage of federal liability (input, default is 50%).

3. Book Valuation

It was noted in the subsection on-capital replacement expenses and annual investment that the company does not have to replace all of its capital goods every year. The expected value of the investment in the standard manufacturing year was then calculated. An estimate of the previous year's investment can be calculated by de-escalating that investment.

This procedure can be continued backward, year by year, to obtain an estimate of the investment that was made in every year in the past. Past years' investments can then be used to determine current book values as discussed in the rest of this subsection.

The current book value of an investment made several years ago has, as a rule*, diminished from its original value due to depreciation.

The fraction by which the initial investment has decreased due to depreciation (denoted *sched* in Figure 10 and below) is a function of the depreciation method used, the lifetime assumed, and the age of the investment. Three depreciation methods (see Reference 34) are available in SAMICS: straight-line, sum-of-the-years-digits, and double declining balance.

The facts that older investments were smaller due to escalation and that they have depreciated due to their age are combined in calculating *book* and *tax book*. These two fractions will generally differ in numerical value because the tax life is less than the accounting life (which is generally equal to the expected useful life) and because accelerated depreciation (double declining balance, for example) is usually used for tax purposes, while straight-line depreciation is used for the accounting books.

Closed-form expressions can be obtained for *book* and *tax book* if the escalation rate is assumed to be constant. SAMICS, however, allows escalation rates to be specified on a yearly basis, so the summations are performed explicitly (see Reference 7, page 205). Figure 11 illustrates the combined effect of the two phenomena. *Book* (or *tax book*) is the sum of the depreciated values as of *time = now*. If the escalation rate is positive or the depreciation is faster than straight-line, or both, the numerical value of *book* will be less than one-half of the lifetime, so that the book value of capital assets (the product of *book* and the current investment) will be less than half of the initial value of capital expressed in current dollars. (This last number is the replacement cost of capital goods, not including the costs of removal and installation.)

4. Depreciation

An estimate of the expected value of the cost of replacing capital goods has been calculated explicitly above. This cost, however, is not what is entered on the corporate income tax return as the *depreciation* of capital during the year. Indeed, the estimated cost of replacing capital assumes that the real value of the company's capital is held constant. Tax laws allow a deduction for a decrease in capital value and also provide further investment incentive (beyond the investment tax credit) by allowing accelerated depreciation methods and shortened tax lives.

The depreciation factor, *dep*, used for computing the depreciation reported on the tax return is obtained in SAMICS by summing the differences between last year's tax book value and this year's over all of the capital assets.

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*The capital value of land is an exception to this rule. Tax laws (see Reference 4) allow land to be carried at its purchase cost or its current market value, whichever is smaller. SAMICS values land at its purchase cost, and assumes that it was purchased (by a lump sum payment) a year or two (the plant construction leadtime plus the plant start-up period) before the start of the standard manufacturing year.

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If the *method* is "straight-line," then

    If the *life* is greater than one year and $0 \leq age \leq life$,

        Sched = 1 $-$ *age* / *life*.

    But if the *life* is less than one year and *age* = 0,

        Sched = 1.

    With any other combinations of *life* and *age*,

        Sched = 0.

If the *method* is "sum-of-the-years-digits", then

    If the *life* is greater than one year and $0 \leq age < life$,

        Sched = 1 $-$ [*age* / (*life* + 1)] * [2 + (1 $-$ *age*) / *life*].

    But if the *life* $\leq$ one year and *age* = 0,

        Sched = 1.

    With any other combination of *life* and *age*,

        Sched = 0.

If the *method* is "double declining balance", then

    Let *T* = the integer part of *life* / 2, and

    If *life* > 2 years and $0 \leq age \leq T$,

        Sched = (1 $-$ 2 / *life*) ** *age*.

    While if *life* > 2, but *T* < *age* < *life*,

        Sched = [(1 $-$ 2/*life*) ** *T*] * [1 $-$ (*age* $-$ *T*)/(*life* $-$ *T*)].

    If *life* = 2 and *age* = 0 or 1

        Sched = 1 $-$ *age* / 2.

    If *life* < 2 and *age* = 0,

        Sched = 1.

    With any other combination of *life* and *age*,

        Sched = 0.

Figure 10.   Depreciation Algorithm, for Computing *Sched*, the fraction by which an investment has depreciated, as a function of *method*, *life*, and *age*.

5. Working Capital

Operation of a company requires working capital, in addition to the capital tied up in land, facilities, and equipment. The working capital requirements can be estimated by a detailed consideration of in-process inventory values, payroll intervals, tax hold-backs, dividend schedules, cash, short-term investments, and so forth. A simpler method, which is similar to the procedure suggested in Reference 35, is to multiply the annual operating expenses by the fraction of a year between payment for input goods and the receipt of payment for finished products. The resulting estimate can be thought of as the amount of
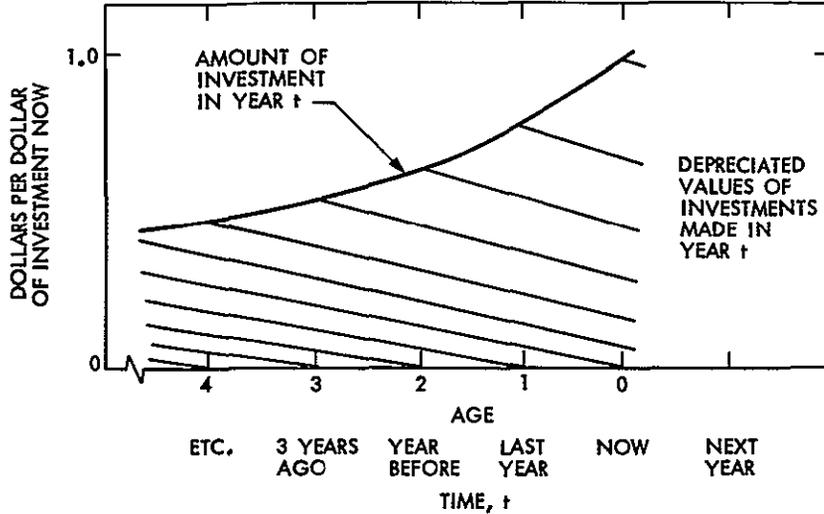
Figure 11. The Combined Effect of Escalation and Depreciation on
Book Values of Capital Investments

capital tied up in the production "pipeline." An estimate produced in this fashion will be far more accurate-than the sometimes-used specified fraction of facilities and equipment capital, which ignores the relationships between working capital, the prices of input products, and the amount of time required to process inputs.

The SAMICS working capital submodel is given by the following equation.

$$WC = OPR * T_{WC}$$

where

WC = working capital required by the hypothetical company

OPR = annual operating expense of the company

T_{WC} = working capital time lag, which is calculated as follows:

$$T_{WC} = t_{rm} + t_p{}^* m + t_{fg} + t_{ar} - t_{ap}$$

where

t_{rm} = time raw materials spend in inventory, on the average, before being used, expressed in years

t_p = time spent in processing, obtained by summing processing times (input) for all processes, expressed in years

m = processing time multiplier (input), to account for delays in the process sequence

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t_{fg} = time finished goods spend in inventory, on the average, before being sold, expressed in years

t_{ar} = accounts receivable turnover time

= time between sale of finished goods and receipt of payment, expressed in years

t_{ap} = accounts payable turnover time

= time between receipt of raw materials and payment for them, expressed in years.

D. OVERHEAD EXPENSES

Much of what is often characterized as overhead has already been explicitly accounted for as the expenses associated with the indirect requirements. There remain, however, a variety of expenses that are necessary to the operation of a company which have not yet been taken into account.

1. Insurance Premiums

Insurance premiums are based on the cost of replacing the insured goods rather than their book values, which is consistent with industry practice. The SAMICS submodel for the annual premium paid by the company is given by the following equation.

$$INS = (FAC + EQUIP + WC * f) * \nu$$

where

INS = annual insurance premiums in the standard manufacturing year

FAC = initial facilities capital

$EQUIP$ = initial equipment capital

WC = working capital

f = insurable fraction of working capital (input)

ν = company insurance rate (input).

It may be noted that if the company is not to be insured to its full replacement value, the company insurance rate could be given an input value that reflects the actual fraction insured. The *company insurance rate* would then be interpreted as the *effective company insurance rate*.

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2. Non-Income (Property) Taxes

Non-income taxes include real estate taxes, inventory taxes, and any other *ad valorem* taxes that are not based on corporate income. The SAMICS submodel estimates these taxes as a specified fraction of the tax book value of the company.

$$OTX = VAL_{tax} * \beta .$$

where

OTX = annual non-income taxes of the company

VAL_{tax} = capital value of the company, as recorded in the books kept for tax purposes

β = non-income tax rate (input).

3. Interest on Corporate Debt

A fraction of the firm's total (accounting) book value is financed by corporate debt. SAMICS assumes that the hypothetical company's fiscal policies are such that this fraction remains constant.

$$INT = VAL_{book} * \frac{\lambda - 1}{\lambda} * i$$

where

INT = annual payment of interest on corporate debt

VAL_{book} = capital value of the company, as recorded in the accounting books

λ = financial leverage, the ratio of total capital to equity capital (input)

i = debt interest rate.

4. Return on Equity

The remaining fraction of the firm's total book value is assumed to be financed by equity capital. In the real world, the return paid to the equity holders depends upon the quantity of manufactured goods sold and the price obtained in the market. In the hypothetical SAMICS world, the quantity sold is specified, and the market price needed to cover all expenses and to provide a specified after-tax rate of return on equity is the primary output.

$$EQR = VAL_{book} * \frac{r}{\lambda}$$

where

EQR = after-tax return on equity

VAL_{book} = capital value of the company

r = rate of return on equity (input)

.λ = financial leverage.

The SAMICS company is assumed to operate in a steady-state condition. Hence, all of the return on equity can be considered to be *distributed earnings* to the equity holders. This assumption is not essential, however: a portion (unspecified, insofar as SAMICS is concerned) could be *retained* by the company and used for other ventures. (See also the discussion on the distribution of the capital resulting from depreciation to steady-state in the one-time costs section.)

5. Amortized One-Time Costs

Each SAMICS firm must produce enough revenue to recover* not only the expenses incurred during steady-state operations, but also the net** excess of costs over revenues during each year that cash flows are not in a "steady-state." These net costs are expressed as a present value as of the start of the standard manufacturing year and then replaced by an annual expense term, which, growing at the rate of general inflation and continuing for a standard capital recovery time, produces the same present value.

$$.AOC = OTC * gcrf(k, T_{cr}, g_t)$$

where

AOC = amortized one-time cost, the annual expense in the standard manufacturing year which, continued for T_{cr} years and increasing according to the general rate of inflation, produces the same present value as *OTC*

OTC = present value, as of the start of the standard manufacturing year, of all of the one-time costs

---

*The SAMIS III computer program provides a switch — the *run.control: steady.state.flag* — which may be turned "on" to avoid the calculation of the one-time costs described in this section. The resultant price would be that which the company would have to receive, after operating for the standard capital recovery time, in order to meet all of its expenses and provide the specified profit, assuming that it is planning to stay in operation for an indefinite period into the future.

**One-time costs occur in a nonuniform fashion over a period of many years. To account for this fact, the SAMICS methodology computes their present values as of the start of the standard manufacturing year. These computations take into account the timing of the expenditures, the escalation rates that determine the dollar amounts of all outlays, and the firm's cost of capital. The resultant present value is the equivalent amount of capital that would be required if it were provided in a lump sum at the start of the standard manufacturing year.

$$\text{gcrf(\ )} = \text{generalized capital recovery factor}$$

$$k = \text{firm's after-tax cost of capital}$$

$$T_{cr} = \text{standard capital recovery time* (input)}$$

$$g_t = \text{rate of general inflation (an input table as a function of time).}$$

The generalized capital recovery factor (see Reference 1, pp. B-12 and B-13) is a modification of the conventional capital recovery factor and accounts for growth of the annual payment at the rate of inflation. It can be defined as the numerical value of the first term in a growing stream of T_{cr} annual cash flows which starts at the beginning of the standard manufacturing year and has a present value of unity. It can be derived by equating the present value of a stream of inflating cash flows with an initial value of $gcrf$ to unity and solving. The following result is obtained.

$$gcrf(k, T_{cr}, g_t) = 1 \left/ \left(1 + \sum_{i=1}^{T_{cr}-1} \left\{ \left[\prod_{t=t_m}^{t_m+i-1} (1+g_t) \right] \middle/ (1+k)^i \right\} \right) \right.$$

where

$$t_m = \text{standard manufacturing year}$$

The complexity of this equation results from allowing the inflation rate to vary from year to year. The SAMIS III computer program takes advantage of the fact that the sum can be expressed in closed form for those periods during which inflation is assumed to be constant.

$$gcrf(k, T_{cr}, g) = \frac{k-g}{1+k} * \frac{1}{1 - \left(\frac{1+g}{1+k}\right)^{T_{cr}-1}} \qquad \begin{cases} \text{if } g_t = g \text{ for all } t \\ \text{and } k \ne g \end{cases}$$

If the inflation rate is zero, this expression reduces to the conventional capital recovery factor.

$$crf(k, T_{cr}) \equiv gcrf(k, T_{cr}, 0) = \begin{cases} k \left/ \left[1 - (1+k)^{-T_{cr}} \right] \right. & \text{if } k \ne 0 \\ 1/T_{cr} & \text{if } k = 0 \end{cases}$$

---

*The nominal value of T_{cr} is infinity, for otherwise the one-time costs would be recovered more than once. Consequently, if the rate of general inflation were constant, the generalized capital recovery factor would be approximately equal to $k - g$. (The subscript on g was dropped to suggest its constancy with respect to time.)

The problem of this subsection has thus been reduced to that of determining the present value of the net excess of "one-time" costs over revenues. The following components have been identified*:

- Land purchase
- Construction of facilities
- Initial installation of equipment
- Investment tax credit
- Accumulation of working capital
- Start-up costs (and revenues)
- Depreciation to steady-state

Suppose that at the $t = T$, a capital expenditure of an amount L is made. This expenditure becomes a part of the capital value of the firm. As this capital good ages, it will decrease** in value***. This decrease is accounted for in the SAMICS methodology by the replacement of capital term, RPL, which has two functions. When the firm is very young, no repairs or replacements are needed, and all of RPL goes**** to the investors, compensating them for the decrease. When the firm is mature, all of RPL is used to maintain the capital stock at its average depreciated value. Between the youth and the maturity of the plant, RPL performs a mixture of these two functions.

The hypothetical investors in a SAMICS firm are "guaranteed" a return on their investment (by the required revenue condition), whether the firm has started manufacturing or not. By the start of the standard manufacturing year, the firm has accumulated an obligation to the investors given by the following equation.

$$OTC = \left[(1+k)^{t_m - T} - 1 \right] * L$$

where OTC = the present value, as of the start of the manufacturing year, t_m, of the obligation to the investors resulting from a capital outlay of L made at time T.

(It may be noted that T could be at or after t_m, as well as before it.)

Unfortunately, the acquiring of capital goods also leads to insurance and property tax expenses, the funds for which must also be obtained from the investors when the expenses occur before the plant is in operation.

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*It is assumed that one-time revenues (and costs) resulting from eventual removal of the factory and salvage of its facilities and equipment will take place so far in the future that, for all reasonable values of the discount rate, their effect on price can be neglected.

**Land is an exception: its value is assumed to remain constant.

***In this context, *value* is equivalent to usefulness, future productivity, or worth; the replacement cost — even the market price of the used good — may increase due to inflation. An economist might call this the "value (in real terms)."

****The usual mechanism for this return *of* capital is expansion — an increase in the capital stock of the company. As a consequence, the investors do not receive dividends, but neither does their stock depreciate. The mechanism is not, however, relevant to the SAMICS methodology.

$$OTC = (1 + k)^{t_m - T} * E$$

where OTC = the present value, as of the start of the manufacturing year, t_m, of the obligation to the investors resulting from an expense of E made at time T.

Present Value of Early Land Purchase

The expenditure for land was calculated in the course of estimating the capital-related expenses on the assumption that it was purchased at the start of the year that contained the start of construction. This expenditure itself is *not* to be considered a one-time cost (even though it occurs only one time), because the value of land stays in the company. Capital *values* are accounted for by the payments made to the suppliers of capital. One-time costs result from the fact that land is purchased before the company starts producing revenue.

At the end of each year after purchase, the company must pay taxes on the land. (SAMICS assumes that the tax rate is β, with the same numerical value as was used in the calculation of "other taxes".) The funds to pay those taxes must come from the suppliers of capital.

The present value of the additional obligation to the capital suppliers resulting from the fact that land must be purchased before the start of the standard manufacturing year is thus given by the sum of two terms.

$$PV_{ELP} = OBL + PTAX$$

where

PV_{ELP} = present value of early land purchase

OBL = accrued obligation due to early need for capital

$PTAX$ = accrued obligation due to early taxes on land.

$$OBL = LAND * \left[(1 + k)^Y - 1\right]$$

where

$LAND$ = expenditure for land

k = firm's after-tax cost of capital

Y = number of years from land purchase to the start of the standard manufacturing year.

$$PTAX = LAND * \beta * \sum_{t=1}^{Y-1} (1 + k)^{Y-t}$$

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where β = non-income tax rate, and the summation stops at Y $-$ 1 because taxes are assumed to be paid near the beginning of the year after they become due.

These equations can be expressed in closed form as follows:

$$PV_{ELP} = \begin{cases} LAND * \beta * (Y - 1) & \text{if } k = 0 \\ LAND * \left\{ \left(1 + \frac{\beta}{k}\right) * \left[(1 + k)^Y - 1\right] - \beta \right\} & \text{if } k \neq 0 \end{cases}$$

Present Value of Early Construction Costs

As with land values, facilities and equipment values are accounted for by the payments made to the suppliers of capital. However, the fact that construction and installation costs are incurred before revenues begin leads to additional obligations to those capital suppliers. In addition, there are property taxes and insurance premiums that must be paid, again before revenues begin. [Release 1 of the SAMIS III computer program makes the following simplifying assumptions: the same tax and insurance rates (not amounts) apply before the start of the standard manufacturing year as afterwards. All facilities construction costs are incurred at the end of the first year of construction. All equipment costs are incurred at the beginning of the last year of construction.]

The submodel for calculation of the present value of early construction and installation costs also generates an estimate of the investment tax credit savings accumulated. It is assumed that all of the available tax credit can be realized, either by carry-forward or by use in a parent company.

Facilities and equipment capital requirements are computed by de-escalation back to the assumed time of occurrence. Insurance premiums are assumed to be paid at the beginning of each year on escalated replacement values. Taxes are assumed to be paid at the end of each year on escalated values (depreciation does not start until the start of manufacturing). Insurance and tax payments made on or after the start of the standard manufacturing year are assumed to be included in the steady-state portion of the model, and are not treated as one-time costs.

The equations for the calculation of the present values are similar to those given above for land, except that the sums are calculated explicitly to allow for the possibility of non-uniform escalation rates. (The book and tax values of land were assumed to remain constant at the purchase cost.)

Present Value of Early Working Capital Investment

It is assumed that all of the working capital is required at the start of the year containing the beginning of the start-up period. The dollar amount of working capital required is deflated to that time. Additional dollar amounts are supplied at the start of each year until the start of manufacturing to keep pace with inflation. As with land, facilities, and equipment, the *amount* of working capital supplied is not considered a one-time cost — only the obligations to the suppliers of capital, insurance premiums, and non-income taxes are.

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Present Value of Start-Up Costs and Revenues

During the start-up period, process yields and production rates can be expected to improve until they approach their steady-state values. As a consequence, direct materials and supplies will be used at a different rate and revenues will be smaller than during steady-state operation. Revenues will also be reduced due to the building up of the steady-state inventory*. Revenues will be increased, on the other hand, by additional by-product income resulting from the increased scrap. (This increase is approximated by assuming all the by-product income normally obtained is from the sale of scrap. When by-product income normally results from the sale of actual by-products, the revenue during start-up will be overestimated.) All expenses other than those of direct materials and supplies, on the other hand, will occur at about the same rate as during steady-state. The SAMICS submodel for start-up costs and start-up revenues reflects these considerations (Reference 4).

$$SUC = (OPR + RPL + INS + OTX + INT + EQR + MIS - D + M * F * D) * T_S$$

$$SUR = REV * (F * T_S - V) + BYP * F * (M - 1) * T_S$$

$$SAV = \tau * \left[(OPR + DEP + INS + OTX + INT + MIS - D + M * F * D) * T_S - SUR \right]$$

where

SUC = total cost during the start-up period

SUR = total revenue during the start-up period

SAV = tax savings

OPR = annual steady-state operating expenses

RPL = annual steady-state capital replacement expenses

INS = annual steady-state insurance premiums

OTX = annual steady-state non-income taxes

INT = annual steady-state interest on corporate debt

EQR = annual steady-state obligation to holders of equity

MIS = annual steady-state miscellaneous expenses (modeled later by the expression $MIS = x * REV + y * OPR + z * VAL_{book}$)

D = annual steady-state direct materials and supplies expenses

---

*Since the in-process inventory starts at zero and builds up to its steady-state value, one might expect a reduction in working capital requirements during start-up. The value of in-process inventory, however, is the sum of the value of raw materials and the value added by labor. The value added by labor is assumed to be applied at the same rate (per unit time) during start-up as during steady-state operation, even though less of it winds up embedded in products being sold. To put it another way, during the start-up period, an estimate of working capital requirements based on the operating expense rate is more meaningful than one based on the value of in-process inventory.

M = average fraction, per unit of production, of steady-state direct materials and supplies rate required during start-up due to reduced yields (nominal value = 1.25)

F = average fraction of the steady-state production rate achieved during the start-up period (nominal value = 0.635)

T_S = length of the start-up period

REV = annual steady-state total revenues

V = steady-state inventory as a fraction of annual sales (nominal value = 0.08)

BYP = annual steady-state by-product income

τ = corporate income tax rate

DEP = annual steady-state depreciation.

SAMICS assumes that these costs and revenues occur at the end of the year containing the start of the start-up period. The net effect is a loss during that period. This loss generates a tax savings, which can either be taken immediately by a "parent" company or carried forward by the hypothetical SAMICS company. The amount of the tax savings is approximated by the tax rate times the amount of the loss. Consequently, the net present value is given by the following equation.

$$OTC = (SUC - SUR - SAV) * (1 + k)^{t_m - t_{su}} * \Phi$$

where

OTC = net present value of start-up costs and revenues

SUC, SUR, SAV, k, t_m = as defined above

t_{su} = the time of the start-up cash flows

Φ = deflator from t_m to t_{su}.

A complication has crept into the analysis: The annual expense rate, REV (which will equal the annual revenue rate as a result of the required revenue condition), has not yet been calculated. Hence, it is necessary to re-express this last result in a different form.

$$OTC = CON + MUL * REV$$

where

CON = that portion of OTC that does not depend upon the total annual revenues

MUL = that portion of OTC that does depend upon REV, divided by REV.

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These two constants are given by the following equations in terms of the variables defined above.

$$CON = \left\{ EQR + RPL - \tau * DEP + (1 - \tau) * [OPR * (1 + y) + INS + OTX + INT \right.$$

$$\left. + z * VAL_{book} - D * (1 - M * F) - F * (M - 1) * BYP] \right\}$$

$$* T_S * (1 + k)^{t_m - t_{su}} * \Phi$$

$$MUL = \left\{ (1 - \tau) * (x - F) * T_S - V \right\} * (1 + k)^{t_m - t_{su}} * \Phi$$

Present Value of Depreciation to Steady-State

As discussed above, the firm's capital replacement expense, *RPL*, accounts for the return of the capital associated with the transition from all new capital goods to mixed new and old capital goods. Obligations to the suppliers of capital, insurance, and non-income taxes, however, have only been calculated on the (smaller) steady-state depreciated value. In addition the depreciation of capital goods during this period of depreciation is larger than during steady-state operations. The term *PV_DEP* is the present value of these expenses on the "excess" capital value during this period.

The actual phenomenon that takes place is quite complicated. Consider Figure 12, which illustrates the way capital values change with time. The dashed line shows the idealized situation in which the value of the facility decreases smoothly to zero over its lifetime, then jumps back to its initial value when it is replaced. (The "sawteeth" result from the same idealization of the value of the shorter-lived equipment.) Capital replacement is actually a stochastic process, as suggested by the wiggly solid line. Neither equipment nor facilities are all replaced at once. Eventually, the capital value will hover in the vicinity of the steady-state average depreciated book value, which was calculated above.

The SAMICS submodel of the variation of capital value with time is a straight-line decrease from the initial value to the steady-state value, followed by the steady-state value itself, as indicated by the non-wiggly solid line in Figure 12. The period over which this decrease takes place is controlled by an input, the standard *depreciation half life fraction*, and runs from the start of the year in which construction ends until the end of the year in which steady-state is "achieved".

The expenses that make up the contribution to one-time costs are, as mentioned above, non-income taxes, insurance premiums, return on capital, and the income tax savings, all on the difference between initial and steady-state capital. Taking inflation into account, the capital value as a function of time, is given by

$$C_t = (C_I - C_{SS}) * \left(1 - \frac{t - t_c}{t_{ss} - t_c} \right) * \Phi_{t_m, t} \quad \text{for } t_c \leqslant t < t_{ss}$$

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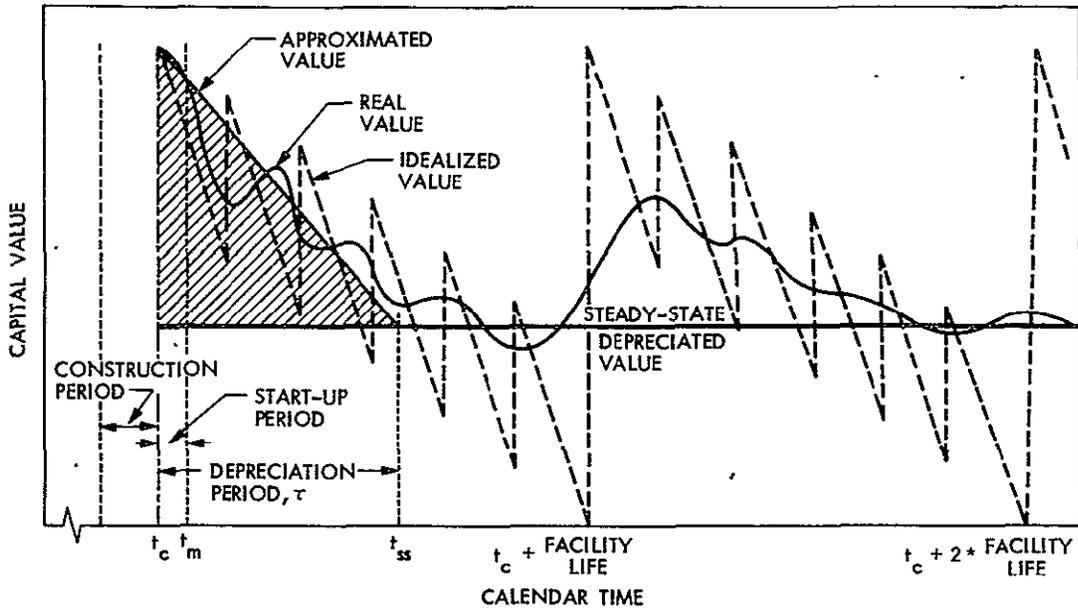
"ONE-TIME" EXPENSES (ON SHADED AREA ONLY) =
NON-INCOME TAXES + INSURANCE PREMIUMS + RETURN ON CAPITAL

Figure 12.   Depreciation to Steady-State. The dashed line shows the variation of capital value
with time in the idealized situation of deterministic depreciation and identical
lifetimes for all equipment. The wiggly solid line illustrates the way the real value
could change with time. The non-wiggly solid line represents the SAMICS model.

where

C_t = book value of facilities and equipment in year t

C_I = initial book value of facilities and equipment

C_{SS} = steady-state book value of facilities and equipment

t_c = time at completion of construction

t_{ss} = time at achievement of steady-state

$\Phi_{t_m,t}$ = inflation factor from t_m to t.

The expenses on the "excess" capital values are then given by

$$INS_t = C_t * \nu * (1 - \tau)$$

$$OTX_t = C_{t-1} * \beta * (1 - \tau)$$

$$IVR_t = \frac{C_{t-1} + C_t}{2} * k$$

$$TAX_t = (C_t - C_{t-1}) * \tau$$

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where

INS_t = insurance premium at time t

OTX_t = non-income taxes at time t

IVR_t = return on investment (debt and equity) at time t

TAX_t = income tax savings at time t

ν = company insurance rate

τ = approximate company income tax rate

β = company non-income tax rate

k = firm's cost of capital.

The combined expense formula is then

$$E_t = C_{t-1} * \left[\beta * (1 - \tau) + \frac{k}{2} - \tau \right] + C_t * \left[\nu * (1 - \tau) + \frac{k}{2} + \tau \right]$$

Each of these expenses must be discounted back to the standard manufacturing year and summed to determine the present value.

$$PV_{DEP} = \sum_{t=t_c}^{t_{ss}} \left[E_t / (1 + k)^{t - t_m} \right]$$

where

PV_{DEP} = present value of one-time costs resulting from expenses on the "excess" capital during depreciation to steady-state

t_m = standard manufacturing year.

Due to the presence of the inflation term, it is not convenient to express this equation in closed form.

6. Corporate Income Taxes

Corporate income taxes are computed on the basis of the company's taxable income. The taxable income is not equal to the return on equity for several reasons. First, the return on equity is defined as the *after-tax* return to the owners of the company. Second,

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the amortized one-time costs constitute a large expense (and consequently, by the required revenue condition, a large contribution to taxable income) which is considered to be paid to the suppliers of capital as a fulfillment of an obligation in addition to the steady-state return on equity and interest on debt. Third, there are technical differences between actual expenses (such as replacement of capital) and tax-deductible expenses (such as depreciation).

Since the taxable income depends upon the total annual expenses (by the required revenue condition), which in turn depend upon the product price, the actual computation of corporate income taxes is performed within the iteration loop discussed in Section E, below. The submodel for that calculation is described here.

$$TAX = tax(TI) - AITC - JTC$$

where

   TAX = corporate income taxes (state and federal)

   TI = taxable income

   $tax(\ )$ = tax function (discussed in more detail below)

   $AITC$ = actual investment tax credit taken

   JTC = job tax credit*.

Taxable income is given by the following two equivalent equations.

$$TI = REV - (OPR - JTC) - OTX - DEP - INS - INT - MIS$$

$$= SALES + BYP - OPR - OTX - DEP - INS - INT - MIS + JTC$$

where

   REV = SALES + BYP = total annual revenues

   $SALES$ = revenue from sale of the company's products

   BYP = revenue from sale of by-products

   OPR = operating expense

   OTX = non-income (property) taxes

   DEP = deductible depreciation on capital goods

   INS = insurance premiums

---

*See Reference 4. Calculation of the job tax credit is not yet implemented in the SAMICS methodology, though the income tax submodel carries it, with a numerical value of zero.

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INT = interest on corporate debt

MIS = miscellaneous expenses (discussed in the next subsection).

The investment tax credit is almost known before entering this calculation, since a value for it was calculated along with the other capital-related expenses. However, tax laws prohibit taking a credit larger than a specified* fraction of the total tax liability in any one year. Since the hypothetical SAMICS company operates in a steady-state, the fact that the law allows carry-forward does not help, so the investment tax credit taken may be smaller than the value previously calculated.

The tax liability (before subtracting tax credits) is computed by the *tax* function as the sum of state and federal taxes. Since state income taxes are deductible expenses on the federal tax return, they are calculated first, then subtracted from the taxable income before federal taxes are calculated. Both tax calculations employ (input) tax rate tables. Federal tax, for example, is calculated** as follows.

$$\text{FED} = \begin{cases} 0.20 * \text{RTI} & \text{if RTI} \leqslant 25{,}000 \\ 5{,}000 + 0.22 * (\text{RTI} - 25{,}000) & \text{if } 25{,}000 < \text{RTI} \leqslant 50{,}000 \\ 10{,}500 + 0.48 * (\text{RTI} - 50{,}000) & \text{if } 50{,}000 < \text{RTI} \end{cases}$$

where

FED = federal tax liability

RTI = taxable income remaining after subtraction of state tax liability.

Since the firm's cost of capital and generalized capital recovery factor depend on the actual average tax rate, they are recalculated after the tax has been computed. It is assumed, however, that the corrections to these two parameters would have a negligible effect on expense components already calculated (equipment payment float in Section C-1 and one-time cost factors in Section D-5) and they are not recomputed***.

7. Miscellaneous Expenses

Miscellaneous expenses are those that are too small (but numerous) or too vague to identify. The SAMICS methodology provides three parameters by which they can be specified as fractions of the total annual expense, of the annual operating expense, of the depreciated book value, or of any combination of these.

$$\text{MIS} = x * \text{REV} + y * \text{OPR} + z * \text{VAL}_{\text{book}}$$

---

*This fraction is a SAMIS III input.
**All of the parameters in this calculation are standard inputs.
***The original computation used the highest marginal tax rates as if they were the average tax rates.

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where

MIS = annual miscellaneous expense

REV = annual revenue = total annual expense

OPR = annual operating expense

VAL_{book} = book value of equipment and facility capital

x = company miscellaneous expense fraction of revenue (input)

y = company miscellaneous expense fraction of operating expense (input)

z = company miscellaneous expense fraction of book value (input).

If the hypothetical SAMICS company has a "parent" corporation that imposes a corporate overhead in addition to the required rate of return on equity, that overhead can most likely be costed by increasing one or more of these miscellaneous expense fractions.

E. TOTAL ANNUAL EXPENSE ITERATION

Some of the annual expenses (amortized one-time costs, income taxes, and miscellaneous expenses) depend partly on the annual revenues, and the annual revenues must (by the required revenue condition) equal the sum of the annual expenses.

If the price-dependent expenses could be expressed in simple enough algebraic forms, simple algebra could be used to find the total annual expense and its component parts. The *tax* function, however, is sufficiently complicated that an iteration procedure is used instead. Initial values for the iteration are obtained by using the highest marginal tax rates in the state and federal tax rate tables as if they were the average tax rates and by assuming that the investment tax credit is not affected by an upper bound. Each iteration requires very little calculation, and very few iterations are required.

F. MANUFACTURED PRODUCT PRICES

If each firm were constrained to produce a single product, and if expense breakdowns by process were not of interest, product prices could be determined by simply dividing the total annual revenues (less the by-product income, if any) by the annual production quantity. However, since SAMICS is designed to be able to handle multiproduct firms, and process-by-process breakdowns are essential to the comparison of competing processes, a more elaborate procedure is used: Total annual expenses for each work station (which do produce single products) are determined, then divided by the work station's annual product quantity to obtain a work station product price. This price is supplied to the subsequent work stations that require the product, multiplied by the quantity required, and summed to produce an *implicit product cost*. Thus, each work station implicitly (that is, no money changes hands), buys the products that it requires from within the firm, and implicitly sells its product to those work stations within the firm that need it. When a work station makes one of the firm's products, the price is inserted in the firm's product prices vector.

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1. Allocation of Overhead to Work Stations

Work stations' direct and indirect expenses (and by-product income) are calculated by using the firm's prices for all expense items (except facilities) and the work stations' quantities. (Work stations' capital-related expenses are calculated in tandem with those of the firm.) These expenses together constitute the work stations' *attributable expenses*.

$$ATT = DIR + IND - BYP + RPL + INS + INT + EQR + OTX$$

where

ATT = attributable expenses

DIR = direct expenses

IND = indirect expenses

BYP = by-product income

RPL = equipment and facilities capital replacement expenses

INS = insurance premiums

INT = interest on corporate debt

EQR = return on equity

OTX = other (non-income) tax expense.

An *overhead allocation fraction* is determined for each work station by dividing its attributable expenses by the sum of all the work stations' attributable expenses.

The overhead expense to be allocated is determined by subtracting from the firm's total annual expense the sum of its by-product income, its procured product expenses, and its total attributable expenses.

$$E = REV - BYP - PPE - ATT$$

where

E = firm's allocable expenses

REV = firm's annual revenue = total annual expense

BYP = firm's by-product income

PPE = firm's procured product expense

ATT = firm's total attributable expenses.

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2. The Price Equation

The price* of each work station's product is then determined from the following equation.

$$PRICE = (P + M + T + F * E - I) / Q$$

where

PRICE = price (per unit) of the work station's product

P = cost of products purchased from other firms for use by this work station

M = implicit cost of products obtained from other work stations within this firm

T = work station's total attributable expenses

F = work station's overhead allocation fraction

E = firm's allocable expenses

I = work station's by-product income.

Q = work station's annual quantity of product produced.

G. SUMMARY OF PRICE CALCULATION EQUATIONS

As with the summary of quantity calculation equations, the equations presented here are not in precisely the same form as they were given above. In an attempt to clarify the development, this section also gives the equations in a somewhat different order.

$$\text{Required Revenue Condition: } REV = EXP$$

where

REV = annual revenues of the company

EXP = annual expenses of the company, including a "reasonable" profit as one of the expenses.

$$REV = SALES + BYP$$

---

*Interpretation of the meaning of "price" is discussed at length in the first footnote of this section (p. 27).

where

SALES = revenues from sales of the company's products

BYP = revenues from sales of the company's by-products.

$$EXP = OPR + RPL + PIOE + PDOE$$

where

OPR = annual operating expenses

RPL = capital replacement expenses

PIOE = price-independent overhead expenses

PDOE = price-dependent overhead expenses.

1. By-Product Income

$$BYP = \Sigma_i |p| * q$$

where

Σ_i = summation over all of the company's needs for expense items in Account D (by-products) with negative prices.

$|p|$ = absolute value of the inflated price of the expense item, calculated from the standard cost account catalog

q = company's total annual production of the expense item (from the firm's TOT vector).

2. Annual Operating Expenses

$$OPR = PPE + \Sigma_i p * q$$

where

PPE = procured product expenses

Σ_i = summation over all of the company's needs for expense items in Accounts B (personnel), C (utilities), D (by-products, but only those with positive prices), and E (commodities)

"p" = price of the expense item, calculated from the price versus quantity table in the standard cost account catalog (using q as the quantity), and inflated to the standard manufacturing year, using the inflation rate table from the catalog

q = company's total annual requirement for the expense item (from the firm's TOT vector).

$$PPE_i = \Sigma_j \ PRICE_{ij} * SQ_{ij}$$

where

PPE_i = annual expense of procuring product i from suppliers outside the company

Σ_j = summation over all suppliers of product i

$PRICE_{ij}$ = price (per unit) of product i when obtained from supplier j

SQ_{ij} = annual quantity of product i obtained from supplier j.

$$PPE = \Sigma_i \ PPE_i$$

where Σ_i = summation over all products procured by the company.

3. Capital Replacement Expenses

$$RPL = RPL_E + RPL_F$$

where

RPL_E = annualized expenditure for replacement of capital equipment

RPL_F = annualized expenditure for replacement of (and major repairs on) facilities.

$$RPL_E = \Sigma_i \Sigma_c \ (INV_{c,def} + R_{c,def}) * IF_c * \frac{N_i}{L_c} * \frac{1}{(1+k)^{v_c}} \ .$$

where

Σ_i = summation over all work stations in the firm

Σ_c = summation over all components in the machine description of process (i.e., work station) i

$INV_{c,def}$ = investment required to replace component c, expressed in component price year dollars (that is, deflated dollars)

$R_{c,def}$ = cost of removing a worn-out component and installing a replacement, expressed in deflated dollars

IF_c = inflation factor to convert component price year dollars to standard manufacturing year dollars

N_i = number of process i machines

L_c = anticipated useful life of component c

v_c = payment-float interval for component c

k = company's discount rate (the average after-tax cost of capital).

$$INSTALL = \Sigma_i \, \Sigma_c \, R_{c,def} * IF_c * \frac{N_i}{L_c} * \frac{1}{(1+k)^{v_c}}$$

where INSTALL = equipment installation cost (to be used later in the one-time cost calculation).

$$INV_{c,def} = C_{c,def} - S_{c,def}$$

where

$C_{c,def}$ = deflated purchase-cost of a replacement component

$S_{c,def}$ = deflated salvage value of a worn-out component.

$$RPL_F = INV_F / L_F$$

where

INV_F = investment required to replace the facilities

L_F = facilities lifetime

$$INV_F = \Sigma_i \, p * q$$

where

Σ_i = summation over all of the company's needs for expense items in Account A (facilities parameters) except land

p = inflated price of the facilities parameter's capital cost estimating relationship expressed by the expense item's price versus quantity table in the standard cost account catalog

q = company's total annual requirement for the facility parameter (from the firm's TOT vector).

4. Capital Values

$$\text{EQUIP} = \Sigma_i \, \Sigma_c \, C_{c,def} * \text{IF}_c * \frac{N_i}{L_c} * \frac{1}{(1+k)^{v_c}}$$

where EQUIP = capital value of equipment, if it were all new, expressed in standard manufacturing year dollars.

$$\text{FAC} = \text{INV}_F$$

where FAC = initial capital value of facilities.

$$\text{WC} = \text{OPR} * T_{WC}$$

where

WC = working capital required by the company

T_{WC} = working capital time lag, the fraction of a year between payment for input goods and receipt of payment for finished goods.

$$\text{LAND} = p * q$$

where

LAND = capital value of land

p = price of land, at the time it was purchased (construction lead time plus startup time before the start of the standard manufacturing year), from the standard cost account catalog

q = company's *land* requirement (from the firm's TOT vector).

$$VAL_{book} = WC + LAND + INV_F * book(L_F, \mu_F) + \Sigma_i \Sigma_c INV_c * book(L_c, \mu_E)$$

where

VAL_{book} = accounting book valuation of company capital assets

μ_F = accounting book depreciation method for facilities

μ_E = accounting book depreciation method for equipment

$book(L, \mu)$ = a function that relates annual investment to depreciated value and accounts for the effects of inflation. [In the absence of inflation, and with μ = "straight line", book(L, μ) would equal (L + 1)/2.]

$$VAL_{tax} = WC + LAND + INV_F * book(TL_F, \mu_{TF}) + \Sigma_i \Sigma_C INV_C * book(TL_C, \mu_{TE})$$

where

VAL_{tax} = tax book valuation of company capital assets

TL_F = tax life of facilities

TL_C = tax life of component C of the process i machine

μ_{TF} = tax book depreciation method for facilities

μ_{TE} = tax book depreciation method for equipment.

5. Capital Related Terms

$$ITC = INV_F * itc_F (TL_F) + \Sigma_i \Sigma_C INV_C * itc_E (TL_C)$$

where

ITC = investment tax credit available to the firm on its corporate income tax, provided the numerical value calculated does not exceed a specified fraction of the company's income tax liability

$itc_F (TL_F)$ = facilities investment tax credit function (current law sets this function identically equal to zero, regardless of the facilities tax life, TL_F)

$itc_E (TL_C)$ = equipment investment tax credit as a function of component tax life.

$$DEP = INV_F * dep(TL_F, \mu_{TF}) + \Sigma_i \Sigma_C INV_C * dep(TL_C, \mu_{TE})$$

where

DEP = annual depreciation of capital assets, for use on the corporate income tax return

. dep(TL, μ_T) = a function that relates annual investment to the legally allowed model of decreases in capital values with age and accounts for the effects of inflation.

6. Price-Independent Overhead Expenses .

$$PIOE = INS + OTX + INT + EQR$$

where

INS = annual insurance premiums

OTX = annual property taxes

INT = annual·interest on corporate debt

EQR = annual return on equity.

$$INS = (FAC + EQUIP + WC * f) * \nu$$

where

f = fraction of working capital which is insured

ν = company insurance rate.

$$OTX = VAL_{tax} * \beta$$

where β = property tax rate.

$$INT = VAL_{book} * \frac{\lambda - 1}{\lambda} * i$$

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where

λ = company financial leverage, the ratio of total capital to equity capital

i = corporate debt interest rate.

$$EQR = VAL_{book} * \frac{r}{\lambda}$$

where r = required rate of return on equity.

7. Price-Dependent Overhead Expenses

$$PDOE = TAX + MIS + AOC$$

where

TAX = corporate income taxes

MIS = miscellaneous company expenses

AOC = amortized one-time costs, an annualized expenditure which, growing at the rate of inflation, will recover the expenses that the company incurs in its early years that it would not incur after it reaches steady-state operation.

$$TAX = tax(TI) - AITC - JTC$$

where

TI = taxable income

tax(TI) = state and federal corporate income tax as a function of taxable income

AITC = actual investment tax credit

JTC = job tax credit (not currently included in model).

$$TI = REV - (OPR - JTC) - OTX - DEP - INS - INT - MIS$$

$$AITC = smaller\ of\ (ITC, \rho * TAX_{FED})$$

where

ρ = maximum investment tax credit fraction (of federal income tax liability) allowed by law

TAX_{FED} = federal income tax portion of tax(TI).

$$MIS = x * REV + y * OPR + z * VAL_{book}$$

where x, y, z = input fractions.

$$AOC = OTC * gcrf (k, T_{cr}, g_t)$$

where

OTC = present value, as of the start of the standard manufacturing year, of all of the one-time costs

k = company's average after-tax cost of capital

T_{cr} =. standard capital recovery time

g_t = rate of general inflation, a standard tabular function of calendar time

$gcrf (k, T_{cr}, g_t)$ = capital recovery factor, generalized to account for inflation.

8. One-Time Costs

$$OTC = PV_{ELP} + PV_{ECC} + PV_{ITC} + PV_{EWC} + PV_{SUC} + PV_{DEP}$$

where

PV_{ELP} = present value of costs associated with the purchase of land prior to the start of revenues

PV_{ECC} = present value of costs associated with construction of facilities and installation of equipment prior to the start of revenues

PV_{ITC} = present value of the tax savings associated with the construction of facilities and initial installation of equipment resulting from the investment tax credit (the numerical value of this factor is negative)

PV_{EWC} = present value of costs associated with the need for working capital prior to the start of revenues

PV_{SUC} = present value of start-up costs and revenues

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PV_{DEP} = present value of costs associated with depreciation of capital assets from initial values to steady-state values.

Early Land Purchase

$$PV_{ELP} = OBL_L + PTAX_L$$

where

OBL_L = present value of obligation to suppliers of capital resulting from the early purchase of land

$PTAX_L$ = present value of taxes on land prior to the start of revenues.

$$OBL_L = LAND * \left[(1+k)^Y - 1 \right]$$

where

k = firm's average after-tax cost of capital

Y = number of years from land purchase to the start of revenues.

$$PTAX_L = LAND * \beta * \sum_{t=1}^{Y-1} (1+k)^{Y-t}$$

$$PV_{ELP} = LAND * \left\{ \left(1 + \frac{\beta}{k}\right) * \left[(1+k)^Y - 1 \right] - \beta \right\} \qquad \text{if } k \neq 0$$

Early Construction Costs, Installation, and Investment Tax Credit

$$PV_{ECC} = OBL_F + PTAX_F + OBL_E + PTAX_E$$

where

OBL_F = present value of obligation to suppliers of capital resulting from the early construction of facilities

$PTAX_F$ = present value of taxes and insurance on facilities prior to the start of revenues

OBL_E = present value of obligation to suppliers of capital resulting from the early purchase and installation of equipment

$PTAX_E$ = present value of taxes and insurance on equipment prior to the start of revenues.

$$OBL_F = FAC * DF_F * \left[(1+k)^{YF} - 1 \right]$$

where

DF_F = deflation factor to reduce FAC to the value appropriate to the time of facility construction

YF = number of years from payment for facilities to the start of revenues.

$$PTAX_F = FAC * DF_i * \left[\nu * (1+k)^{YF} + \Sigma_{t=TCC+1}^{t_m-1} IF_{F,t} * (\nu + \beta) * (1+k)^{t_m-t} \right]$$

where

TCC = time at start of construction

t_m = standard manufacturing year (start of revenues)

$IF_{F,t}$ = inflation factor for facilities to raise insurance premiums and taxes to their inflated values.

$$OBL_E = (EQUIP + INSTALL) * DF_E * \left[(1+k)^{YE} - 1 \right]$$

$$PTAX_E = (EQUIP + INSTALL) * \left[\nu * (1+k)^{YE} + \Sigma_{t=TEC+1}^{t_m-1} IF_{E,t} \right.$$

$$\left. * (\nu + \beta) * (1+k)^{t_m-t} \right]$$

where DF_E, YE, TEC, and $IF_{E,t}$ are defined for equipment like their facilities counterparts.

$$PV_{ITC} = -FAC * DF_F * RITC_F * (1+k)^{YF} - EQUIP * DF_E * RITC_E * (1+k)^{YE}$$

where

$RITC_F$ = investment tax credit rate for facilities (zero under current tax law)

$RITC_E$ = investment tax credit rate for equipment, assuming for this calculation that all equipment qualifies for the maximum credit (a simplifying approximation).

$$PV_{EWC} = OBL_{WC} + PTAX_{WC}$$

where

OBL_{WC} = present value of obligation to suppliers of capital resulting from the need for the deflated amount of working capital at the start of the startup period and the inflationary delta in working capital each successive year prior to the start of revenues

$PTAX_{WC}$ = present value of taxes and insurance on working capital supplied prior to the start of revenues.

$$OBL_{WC} = WC * DF * \left\{ \left[(1+k)^{t_m - TW} - 1 \right] + g_{TW} * \left[(1+k)^{t_m - TW - 1} - 1 \right] \right.$$

$$+ (1 + g_{TW}) * g_{TW+1} * \left[(1+k)^{t_m - TW - 2} - 1 \right]$$

$$+ (1 + g_{TW}) * (1 + g_{TW+1}) * g_{TW+2} * \left[(1+k)^{t_m - TW - 3} - 1 \right]$$

$$\left. + \ldots \right\}$$

where

DF = deflation factor to express WC in TW year dollars

t_m = standard manufacturing year (start of revenues)

TW = time at which working capital is first needed

g_t = inflation rate during year t

Summation continues until the exponent of (1 + k) reaches zero.

$$PTAX_{WC} = WC * DF * \left\{ f * \nu * (1+k)^{t_m - TW} \right.$$

$$+ \left[f * \nu * (1 + g_{TW+1}) + \beta \right] * (1+k)^{t_m - TW - 1}$$

$$+ \left[f * \nu * (1 + g_{TW+1})(1 + g_{TW+2}) + \beta * (1 + g_{TW}) \right] * (1+k)^{t_m - TW - 2}$$

$$\left. + \ldots \right\}$$

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where summation continues until the exponent of (1 + k) reaches zero.

Start-Up Costs and Revenues

$$PV_{SUC} = (SUC - SUR - SAV) * (1 + k)^{t_m - t_{su}} * \Phi$$

where

SUC = total costs during start-up

SUR = total revenues during start-up

SAV = tax savings during start-up

t_{su} = time of start-up cash flows

Φ = deflator from t_m to t_{su}.

$$SUC = (OPR + RPL + INS + OTX + INT + EQR + MIS - D + M * F * D) * T_S$$

where

OPR = annual steady-state operating expenses

RPL = annual steady-state capital replacement expenses

INS = annual steady-state insurance premiums

OTX = annual steady-state non-income taxes

EQR = annual steady-state obligation to equity holders

MIS = annual steady-state miscellaneous expenses

D = annual steady-state materials and supplies expenses

M = average fraction, per unit of production, of steady-state direct materials and supplies rate required during start-up due to reduced yields

F = average fraction of steady-state production rate achieved during start-up

T_S = length of the start-up period.

$$SUR = REV * (F * T_S - V) + BYP * F * (M - 1) * T_S$$

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where

REV = annual steady-state total revenues

V = steady-state inventory as a fraction of annual sales

BYP = annual steady-state by-product income.

$$SAV = \tau * [(OPR + DEP + INS + OTX + INT + MIS - D + M * F * D) * T_S - SUR]$$

where

τ = appropriate corporate income tax rate

DEP = annual steady-state depreciation

$$PV_{SUC} = CON + MUL * REV$$

where

$$CON = \left\{ EQR + RPL - \tau * DEP + (1 - \tau) * [OPR * (1 + y) + INS + OTX \right.$$

$$+ INT + z * VAL_{book} - D * (1 - M * F) - F * (M - 1) * BYP] \right\}$$

$$* T_S * (1 + k)^{t_m - t_{su}} * \Phi$$

$$MUL = \left\{ (1 - \tau) * (x - F) * T_S - V \right\} * (1 + k)^{t_m - t_{su}} * \Phi$$

and x, y, z are parameters of the miscellaneous expense submodel.

Depreciation to Steady-State

$$PV_{DEP} = (1 + k)^{t_m - t_c} * \sum_{t=t_c}^{t_{ss}} \left[E_t / (1 + k)^{t - t_c} \right]$$

where

t_c = time at completion of construction

E_t = expenses in year t due to the fact that early capital values are higher than the eventual average depreciated capital values.

$$E_t = \begin{cases} C_{t-1} * \left[\beta * (1 - \tau) + \frac{k}{2} - \tau \right] + C_t * \left[\nu * (1 - \tau) + \frac{k}{2} + \tau \right] & \text{for } t_c + 1 \leq t \leq t_{ss} \\ \\ C_t * \nu * (1 - \tau) & \text{for } t = t_c \end{cases}$$

$$C_t = (C_I - C_{SS}) * \left(1 - \frac{t - t_c}{t_{ss} - t_c} \right) * \Phi_{t_m, t}$$

where

C_I = initial facilities and equipment capital

C_{SS} = steady-state facilities and equipment capital

t_{ss} = time at which steady-state is "reached".

$$C_I = FAC + EQUIP$$

$$C_{SS} = VAL_{book}$$

$$t_{ss} = \text{roundup} (t_m - T_S + h * L_F)$$

where

h = (input) depreciation half-life fraction

$\text{roundup}(x)$ = next integer up from x, unless x is already an integer.

9. Total Annual Expense Iteration

Iteration Constants

$$REV = EXP$$

where

$REV = SALES + BYP$

$EXP = OPR + RPL + PIOE + PDOE$

and where

$PIOE = INS + OTX + INT + EQR$

$PDOE = TAX + MIS + AOC$

Hence,

$$SALES = OPR + RPL + INS + OTX + INT + EQR + TAX + MIS + AOC - BYP$$

To reduce the amount of calculation required in the iteration loop, the first six terms on the right are combined into the iteration constant denoted A.

$$A = OPR + RPL + OTX + INS + INT + EQR$$

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Taxable income, *TI*, is not identical to *REV* or to *SALES*, but is given by

$$TI = SALES + BYP - OPR - OTX - DEP - INS - INT - MIS - JTC$$

The price-independent portions of the right hand side of this equation are combined into the iteration constant denoted *B*.

$$B = BYP - OPR - OTX - DEP - INS - INT$$

Initial Estimates

An initial estimate of *SALES* is obtained by expanding the price-dependent expenses. *MIS* and *AOC* and by approximating *TAX*. Again collecting constant terms and solving for *SALES* gives the following.

$$C = A - BYP + x * BYP + y * OPR + z * VAL_{book} + CON + MUL * BYP$$

where C = A plus price-independent portion of price-dependent expenses.

$$D = B - x * BYP - y * OPR - z * VAL_{book}$$

where D= price-dependent portion of price-dependent expenses.

$$TAU = S + (1 - S) * F$$

where

TAU = combined federal and state corporate income tax rate

S = (largest marginal) state income tax rate

F = (largest marginal) federal income tax rate

AITC = ITC

JTC = 0.0

$$SALES = \frac{C + TAU * D - AITC - (1 - TAU) * JTC}{(1 - x) * (1 - TAU) - MUL}$$

Improved Estimates

$$MIS = x * (SALES + BYP) + y * OPR + z * VAL_{book}$$

$$AOC = CON + MUL * (SALES + BYP)$$

$$TAX_S = tax_S(TI)$$

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where

TAX_S =· state corporate income tax ·

TI = taxable income ·

$tax_S( )$ = state corporate·income tax function.

$$TI = SALES + B - MIS + JTC$$

$$TAX_F = tax_F (TI - TAX_S)·$$

where

TAX_F = federal corporate income tax, before reduction by available tax credits

$tax_F( )$ = federal corporate income tax function.

$$AITC = smaller of (ITC, TAX_F * \gamma)$$

where γ = maximum fraction of federal income tax liability that can be deducted as an investment tax credit.

$$TAX = TAX_S + TAX_F - AITC - JTC$$

$$TAU = TAX / TI$$

$$SALES = A + MIS + AOC + TAX - BYP$$

where SALES = new estimate of revenues from sales of the company's products, for use in the next iteration.

Total Overhead Expenses

$$TOE = OTX + INS + AOC + INT + EQR + TAX + MIS$$

where TOE = company's total overhead expenses.

10. Product Price

Allocation of Overhead to Work Stations

$$ATT = \Sigma_i ATT_i$$

where

ATT = sum of all expenses in the firm that can be attributed to work stations

Σ_i = summation over all work stations in the firm

ATT_i = sum of all expenses that can be attributed to the process i work station.

$$ATT_i = OPR_i + RPL_i + INS_i + INT_i + EQR_i + OTX_i$$

where all the terms on the right-hand side are the process i work station's counterparts to the corresponding company expensés, except that INS_i does not include insurance on working capital.

$$OAF_i = ATT_i / ATT$$

where OAF_i = fraction of the company's allocable expenses to be allocated to the process i work station.

$$ALLOC = EXP - BYP - ATT - PPE$$

where $ALLOC$ = annual company expenses which have not already been attributed to work stations.

Price

$$PRICE_i = (PPE_i + IPC_i + ATT_i + OAF_i * ALLOC - BYP_i) / Q_i$$

where

$PRICE_i$ = price per unit that the company must receive for the product of process i

PPE_i = cost of products procured for the process i work station by the company from suppliers outside the company

IPC_i = implicit product cost; that is, the amount that the process i work station would have to pay to other work stations within the company if intra-company transactions were required by management policy

Q_i = annual quantity of the process i product manufactured by its work station.

$$PPE_i = \Sigma_k \Sigma_j PRICE_{kj} * FS_j * Q_i / (Y_{ik} * IR_{ik})$$

where

Σ_k = summation over all products k required from outside the company by process i

Σ_j = summation over all suppliers j of product k

$PRICE_{kj}$ = price of product k when bought from supplier j

FS_j = fraction of the company's need for product k which is procured from supplier j

Y_{ik} = manufacturing yield of process i with respect to product k

IR_{ik} = ideal ratio of product i to product k.

$$IPC_i = \Sigma_j \, PRICE_j * Q_i \, / \, (Y_{ij} * IR_{ij})$$

where Σ_j = summation over all products j obtained from other work stations within the company by the process i work station.

Section VI

Profit, Markup, and Energy Payback Time

Profit, expressed as a percentage of the price, is an output of the SAMICS methodology. Its value is controlled by the specified (input) rate of return on equity.

$$\text{PROFIT} = \frac{\text{EQR}}{\text{REV}} * 100\%$$

where

PROFIT = firm or work station profit, expressed as a percentage of gross annual revenue

EQR = firm or work station return on equity, determined by multiplying the equity portion of the book value of capital by the (input) rate of return on equity

REV = firm or work station annual revenue. In the case of a work station, this revenue is implicit.

It should be noted that this expression for profit does not include a contribution from the amortization of one-time costs, which is also paid to the equity holder.

Markup is also an output. Its value is given by the following expression.

$$\text{MARKUP} = \frac{\text{REV}}{\text{DIR} + \text{PPE}}$$

where

MARKUP = the number by which the direct expenses (including the cost of input products) must be multiplied to obtain the total annual expenses of a work station or of the firm

REV = total annual expenses = annual revenues

DIR = direct expenses of the work station or firm

PPE = annual cost of products required by the work station or firm.

Another ratio of interest in the particular case of application to the solar array industry is the amount of time that the arrays produced must operate in order to recover the energy that went into manufacturing.

$$PBT = \frac{Energy}{f * IS * pbtf}$$

where

PBT = energy payback time for the firm or a work station

Energy = amount of the natural resource expense item *energy* needed annually

f = fraction of the industry's need for the firm's product which is supplied by this firm

IS = industry size, in peak-watts per year

pbtf = standard payback time factor, which accounts for the conversion from peak-watts of capability manufactured to watt-hours of energy produced by the product over the average year of its use.

The energy payback time is only of passing interest unless it turns out to be longer than the expected lifetime of the solar arrays produced. In that unlikely case, the process sequence under investigation would not be suitable for manufacturing solar arrays intended to displace significant amounts of conventional energy generation capacity.

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Appendix

Nominal Values of Standard Parameters

Nominal numerical values of standard parameters are given below. The Cost Account Catalog (see Reference 5, Volume I, and Reference 6) is too voluminous to include here, even though it contains the tabular functions that express the detailed submodels (Reference 5, Volume II) for prices versus quantities, indirect requirements, and facilities capital costs. The catalog is volatile in the sense that it will always be subject to updating and expansion; it is recommended that the interested reader obtain a printout of the latest edition from the computer data file.

Accounts Payable Turnover Time   0.09 year (=32.9 days)
  Average time from receipt of raw materials until payment for them.

Accounts Receivable Turnover Time   0.10 years (=36.5 days)
  Average time from sale of finished goods until receipt of payment.

Base Year   1975
  Prices of products are deflated to the start of this calendar year for purposes of comparison by using the *inflation rate table*.

Capital Recovery Time   1.0E20 (=10^{20}) years
  The time period over which one-time costs are recovered. (The value 1.0E20 is a computer approximation to infinity.)

Construction Lead Time   2.0 years
  Time required to build the facility and install the equipment, taken to immediately precede the *start-up period*. Land is assumed to be purchased at the start of the year in which construction begins.

Debt Interest Rate   9.25%/year
  Interest on corporate debt is estimated by multiplying this number by the debt portion of the value of capital goods as recorded in the company's accounting books.

Depreciation Half Life Fraction   0.5
  The fraction of the *facility life* at which the initial capital value of the firm is assumed to reach the steady-state depreciated book value (used in the submodel to estimate the one-time costs of depreciation to steady-state).

Epsilon   0.001
  A "small number" used in convergence testing and in rounding. All comparisons are relative, not absolute.

Equipment Book Depreciation Method   "straight-line"
  Specifies the formula to be used to depreciate the capital value of a machine component in a company's accounting books. ("Double declining balance" and "sum-of-the-years-digits" are also available.)

Equipment *Inflation Rate Table*   6% / year
   The escalation rate for equipment capital costs. Each equipment component may have
   its own annual table.

Equipment Tax Depreciation Method   "double declining balance"
   Specifies the formula to be used to depreciate the capital value of a machine component
   in a company's tax records. ("Straight-line" and "sum-of-the-years-digits" are also
   available).

Expense Item *Inflation Rate Table*   . varies
   Escalation rate table for each expense item.

Expense Item *Price vs. Quantity Table*   varies
   A piece-wise linear function of purchase price versus annual quantity purchased, which
   is then escalated from the expense item's *price year* to the standard *manufacturing year*
   by use of the expense item's *inflation rate table*.

Facilities Book Depreciation Method   "straight-line"
   Specifies the formula to be used to depreciate the capital value of the company facilities
   in its accounting books. ("Double declining balance" and "sum-of-the-years-digits"
   methods are also available.)

Facilities Inflation Rate Table   6% / year
   The escalation rate for facilities capital costs. An annual table may be used.

Facilities Investment Tax Credit Flag   "off"
   A switch for calculation of facilities investment tax credits. Current tax law does not
   allow investment tax credits on facilities (Reference 4).

Facilities Tax Depreciation Method   "double declining balance"
   Specifies the formula to be used to depreciate the capital value of the company facilities
   in its tax records. ("Straight-line" and "sum-of-the-years-digits" methods are also
   available.)

Facility Life   40 years
   The average expected useful life of building components, etc.

Federal Income Tax Table	Taxable Income	Marginal Tax Rate
	Less than $25,000	20%
	$25,000 − $50,000	22%
	More than $50,000	48%

Federal corporate income tax liability, before application of tax credits, is computed
from this table.

Finished Goods Inventory Time   0.04 years (=2 weeks)
   Average time from completion of manufacturing until sale of finished goods.

Indirect Requirement *Relative Quantity Table*   varies
   A piece-wise power function (using the indirect requirement *exponent*) of the amount of
   an expense item indirectly required to support a total annual amount of another ex-
   pense item.

Industry *Final Product Reference* varies
    The final (hardware) product of interest, which must be the product manufactured by some process.

Industry *Hardware Performance* varies
    The relationship between the industry *objective* and the industry *final product quantity* stating how many industry *production units* are obtained from each of the industry *final product units*. For example, the industry's *hardware performance* might be 104.2 (peak watts per solar module).

Industry *Objective* "new photovoltaic power capability"
    A functional description of what the industry produces, expressed in industry *production units*.

Industry *Production Units* "peak watts per year"
    The units in which the industry *objective* is expressed.

Inflation Rate Table

Year	≤ 1974	1975	1976	≥ 1977
Rate	6%	7.1%	4.7%	6%

    The annual rate of general inflation (based on the Department of Commerce's "GNP deflator"), using historical data where available, projections where not.

Insurable Percentage of Working Capital 100%
    The fraction of working capital that is insured (cash and accounts receivable, for example, are not).

Insurance Rate 4%
    Insurance premiums are estimated by multiplying this number by the value of capital goods as recorded in the company's accounting books.

Integral Machines Flag "on"
    A switch for ensuring that small hypothetical SAMICS companies do not use fractional machines.

Investment Tax Credit Bottom Life 3 years
    The tax life beyond which the *ITC lower fraction* of the full *investment tax credit rate* may be taken, below which no investment tax credit may be taken.

Investment Tax Credit Middle Life 5 years
    The tax life beyond which the *ITC upper fraction* of the full *investment tax credit rate* may be taken.

Investment Tax Credit Rate 11%
    Assumes (see Reference 4) that the company contributes to an employee stock ownership plan.

Investment Tax Credit Top Life 7 years
    The tax life beyond which the full *investment tax credit rate* may be taken.

ITC Lower Fraction   1/3

The fraction of the full *investment tax credit rate* which may be taken if the tax life is between the *investment tax credit bottom life* and the *investment tax credit middle life*.

ITC Maximum Percentage   50%

The maximum proportion of the federal income tax liability (before applying tax credits) which can be taken as an investment tax credit in any one year.

ITC Upper Fraction   2/3

The fraction of the full *investment tax credit rate* which may be taken if the tax life is between the *investment tax credit middle life* and the *investment tax credit top life*.

Leverage   1.2

The ratio of total capital to equity capital in a company.

Manufacturing Year   1986

The calendar year for which the manufacturing operation is to be evaluated. Differential inflation (i.e., escalation) rates can cause the prices and expenses estimated to depend on this parameter, even when expressed in terms of *base year* dollars.

Miscellaneous Expense Percentage of Book Value   0% / year

Contribution to miscellaneous expenses from those contributors that depend upon the value of capital goods, expressed in terms of the value recorded in the company's accounting books.

Miscellaneous Expense Percentage of Operating Expense   4%

Contribution to miscellaneous expenses from those contributors that depend on the company's operating expenses.

Miscellaneous Expense Percentage of Revenue   3%

Contribution to miscellaneous expenses from those contributors that depend on annual revenue of the company.

Other Tax Rate   2% / year

Inventory, real estate, and other non-income taxes are estimated by multiplying this number by the value of capital goods as recorded in the company's tax records.

Payment Float Interval   0.0 years

Time between receipt of a machine component and payment for it.

Percent of Capacity   100%

The proportion of design capacity at which a company operates.

Processing Time Multiplier   2.0

Average time goods spend in in-process inventory is estimated by multiplying the sum of the times required at each work station by this number. Its appropriate numerical value depends upon how completely the manufacturing process sequence is described.

Rate of Return on Equity   20% / year

 Annual return on equity is specified to be the product of this number and the equity portion of the value of capital goods as recorded in the company's accounting books. This rate should be interpreted as the weighted average of the (higher) rate paid on common stock and the (lower) rate paid on preferred stock.

Raw Materials Inventory Time   0.04 years (=2 weeks)

 Average time from payment for raw materials until first usage in manufacturing.

Shift Multiplier   4.7

 The number of person-years required to supply one person per shift. (In Release 1 of the SAMIS III computer program, this parameter is built in and cannot be changed by input. In a later release, its component factors will be inputs and it will be computed from those components.)

Solar Energy Usage Percentage   20% (average watts/ peak-watts)

 The average number of watts generated during the life of the solar array for each peak watt of capacity. The actual value of this parameter depends upon the design and location of the application in which the array is installed and on operating policies used in that application, all of which are outside the scope of the SAMICS methodology.

Start-Up Direct Commodity Usage Fraction   1.25

 The average fraction of the steady-state direct materials and supplies usage rate during start-up, considering that manufacturing yields tend to be lower during start-up.

Start-Up Period   1.0 years

 Time during which the plant suffers reduced manufacturing yields and production rates prior to the standard *manufacturing year*.

Start-Up Production Fraction   0.635

 The average fraction of the company's steady-state production rate that is achieved during start-up.

State Income Tax Rate Table   **Taxable Income   Marginal Tax Rate**
                                                         Any amount   4%

 (Reference 5, Volume II, gives 1976 state income tax rate tables for all 50 states and the District of Columbia.) State corporate income tax liability is computed from this table.

Steady State Flag   "off"

 A switch that allows SAMICS to omit calculation of "one-time costs" and their implications on product prices.

Tax Life Fraction   2/3

 The lifetimes of capital goods, for use in computing tax book values and depreciation tax deductions, are computed by multiplying expected useful lives by this fraction, then rounding up to the next integer.

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All page numbers are in Volume II unless otherwise indicated. Symbols are followed by their meaning and a cross reference to the relevant concept.