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Array Project
5101-93

DOE/JPL-1012-79/5
Distribution Category UC-63b

A Normative Price for a Manufactured Product: The SAMICS Methodology

Volume I: Executive Summary

Robert G. Chamberlain

January 15, 1979

Prepared for
U.S. Department of Energy
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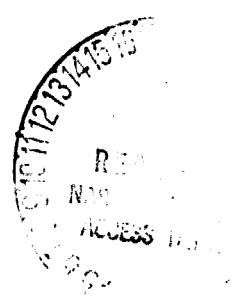

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Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the U.S. Department of Energy by agreement with the National Aeronautics and Space Administration.

The JPL Low-Cost Solar Array Project is sponsored by the Department of Energy (DOE) and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.

Acknowledgements

Donald B. Bickler deserves first mention in these acknowledgements. Without his continued encouragement, especially during the formulative stage of development, and his insistence that we avoid rules of thumb whenever possible, the SAMICS methodology would not be as widely applicable nor as thoroughly validated as it now is.

Several people, specifically Bruce L. Kleine, James W. Doane, and David C. Crocker, contributed very important ideas in the earliest stages of development. The Leontief formulation for calculation of indirect requirements resulted from discussions with Bruce Kleine. The financial model of the firm is based, to some extent, on the model Jim Doane developed for evaluating the cost of energy from utility-owned solar electric systems (Reference 1). The process model and the one-time cost model followed suggestions and critiques provided by Dave Crocker.

Numerous technical discussions with Robert W. Aster resulted in clarification and improvement of many of the detailed computational algorithms, especially those connected with convergence of the indirect requirement calculation. He also developed the Interim Price Estimation Guidelines (Reference 2), which was based on the SAMICS methodology, and consists of a simplification suitable for manual calculation (see also Reference 3). His constructive criticism in the later stages of development contributed greatly to the validity and usefulness of SAMICS.

Technical suggestions by Chester S. Borden, Guy M. Lohman, and Paul J. Firnett have also contributed to the final product.

Theodore Barry and Associates, a management consulting firm, was engaged to critique the methodology and to develop the cost account catalog, the indirect requirements matrix functions, and the capital cost estimating relationships (References 4, 5, and 6). The contributions of the following individuals are especially appreciated: Robert J. Bullemer, James B. Ayers, John Day, David Donovan, and Lawrence Rubenacker. (At the time of this writing, Theodore Barry and Associates is comparing the results of applying the SAMICS methodology, as implemented in the SAMIS III computer program, to conceptual point designs of three manufacturing plants prepared by conventional methods.)

The SAMICS methodology has been implemented by a computer program, SAMIS III. I would like to express my appreciation to Donald A. Heimburger, Marcia A. Metcalfe, Muriel H. Horton, and David G. Weamer (as well as Paul J. Firnett and Bruce Kleine) for their assistance in coding, and to Cleo Benson, Judy Bevan, Lyn Morris, and Madre Tillman for their work on the many stages of the design document (Reference 7). A very important silent partner in the evolution of the program design was the Software Design and Documentation Language processor (Reference 8), developed at JPL by Henry Kleine.

Many other individuals have also contributed to the development and application of the SAMICS methodology. Among these are Brian D. Gallagher, Dale R. Burger, Timothy Stevens, and Suresh Balakrishnan.

SAMICS would not exist if it had not been supported by Harold L. Macomber, Manager of Project Analysis and Integration; his successor, William T. Callaghan; and Robert G. Forney, Manager of the Low-Cost Solar Array Project.

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.

Introduction

What must the market price for photovoltaic solar modules be to cover the costs of manufacturing and make a reasonable profit? The Solar Array Manufacturing Industry Costing Standards (SAMICS) provide a standardized procedure and data base to answer that question.

The SAMICS methodology is quite general — application to production-line manufacturing outside the solar array industry is expected to require only relatively minor augmentation of the data base.

This executive summary* contains a discussion of capabilities and limitations, a non-technical overview of the methodology, and a description of the input data which must be collected. It also describes the activities that have been and are being taken to ensure validity of the results and contains an up-to-date bibliography of related documents.

Background

The Solar Array Manufacturing Industry Costing Standards were developed to provide a fair, consistent, reliable way of comparing manufacturing processes being developed by dozens of Low-Cost Solar Array (LSA) Project subcontractors. In addition to providing guidance on the setting of research priorities, SAMICS was intended to help assess the progress of the LSA project toward its hundred-fold cost reduction goal and to determine the price implications of some of the possible governmental actions that might be taken.

Even within the confines of an ongoing, well-established, full-scale industry, estimation of the costs of manufacturing is a difficult undertaking. The solar array industry is even more challenging, since it is expected to increase in capacity by several orders of magnitude over the next few decades. There is no *a priori* reason to expect current overhead or markup ratios to be applicable to the solar array industry of the future. In particular, the wide range of manufacturing process alternatives being investigated by LSA subcontractors implies different overhead structures for different process sequences.

The approach taken by SAMICS is conceptually very simple and fundamental: describe the direct requirements of each manufacturing process; determine the personnel, facilities, utilities, materials, supplies, and number of machines needed to produce a specified annual amount of the final product; then infer the facilities, indirect personnel, and so forth that are needed to support the totality of the direct requirements. To obtain a realistic result, many of the complications of the real world are carefully modeled. Those complications, however, are internal to the model: a user need only describe the manufacturing process sequence and apply SAMICS (which is available both as a manual procedure and as a computer program) to produce an estimate of the market price that must be received to obtain a specified profit. Detailed manufacturing cost breakdowns are developed along the way. This procedure is illustrated in Figure 1.

*This summary is based on a paper (Reference 9) presented at the Thirteenth IEEE Photovoltaics Specialists' Conference, held in Washington, D.C., June 5-8, 1978.

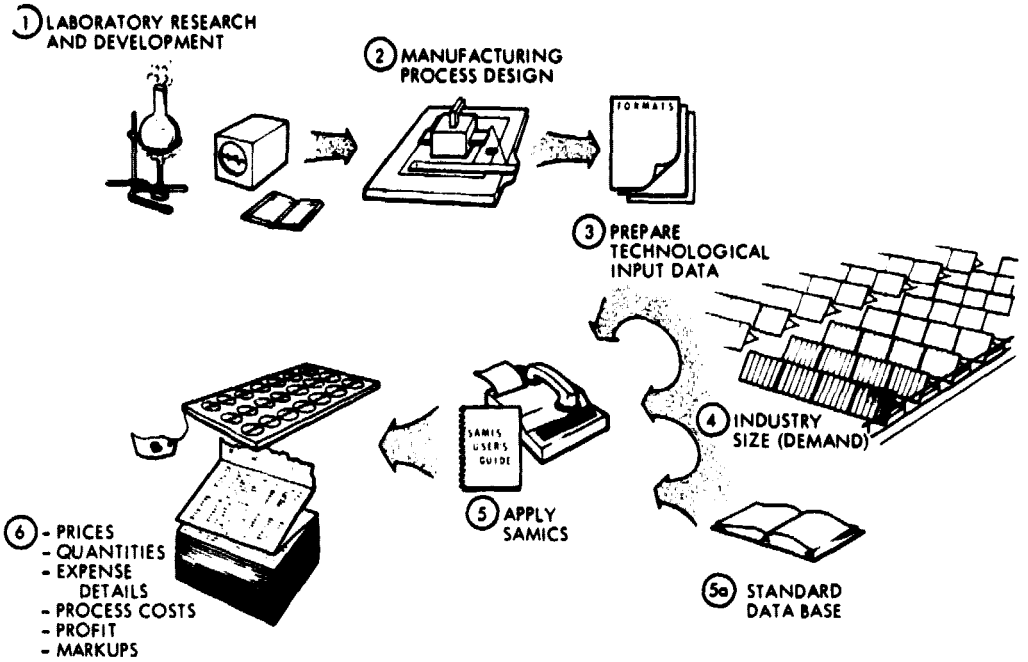

Figure 1. The SAMICS Approach. (1) Use laboratory research and development to identify and (2) define the direct requirements of new manufacturing process steps. (3) Combine these process descriptions with descriptions of existing processes to define complete manufacturing process sequences. (4) Assume an industry size and (5) apply the SAMICS methodology. Internal to the methodology, use (5a) the standardizing assumptions and data base to infer facilities, indirect personnel, depreciation, corporate income tax, and all other components of overhead, including profit. The results are (6) prices, quantities, and detailed breakdowns.

Capabilities and Limitations

The SAMICS methodology is very general, and is expected to be usable in virtually any manufacturing industry (see Figure 2). SAMICS can be used to estimate the manufacturing costs and product prices associated with process alternatives in the context of complete manufacturing sequences. It can also be used to assess the impact of changes in financial parameters, such as costs of input goods or services, inflation rates, tax policies, interest rates, and required return on equity. Economies of scale can also be investigated, as all costs and indirect requirements are described as functions of annual quantities.

SAMICS is limited, however, by a number of underlying assumptions. Perhaps the most important of these limitations is the fact that the market interaction of supply and demand is ignored: demand is assumed to be known, steady over time, and unaffected by the resultant SAMICS price estimate. That is, the SAMICS price is what the hypothetical industry would have to be able to charge if it were to recover all of the costs of manufacturing and make the specified profit. There is no guarantee that this price would ever actually occur in the market.

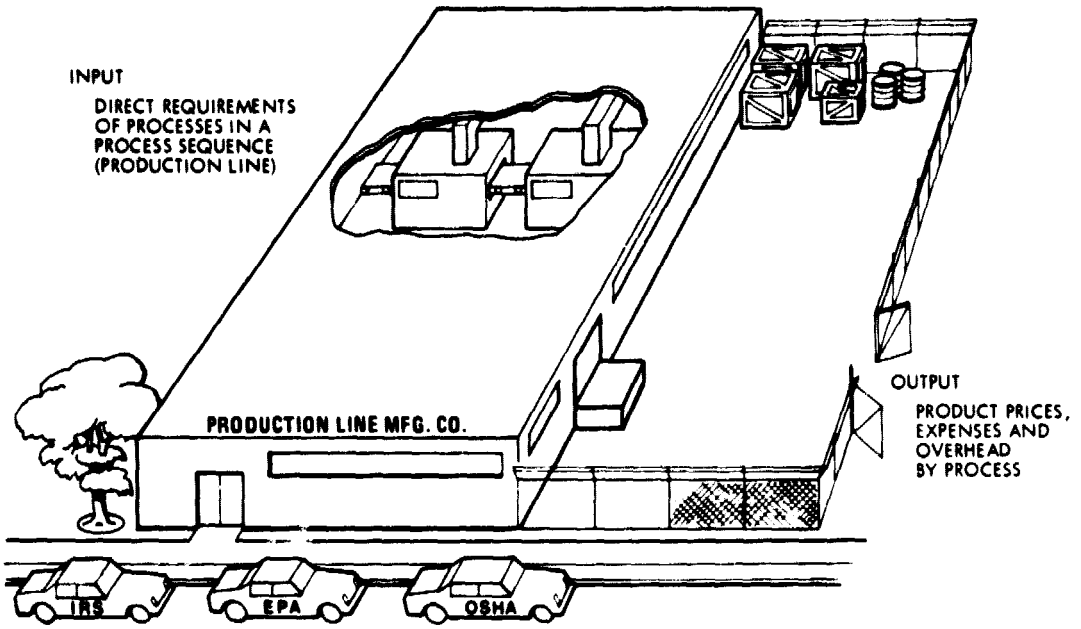

Figure 2. SAMICS Capabilities. SAMICS provides estimates of product prices and process-by-process expenses for a specified sequence of well-defined manufacturing process steps in a standardized estimating environment. SAMICS is not restricted in applicability to the manufacturing of solar arrays, but does assume dedicated production lines. In addition to allowing comparison of competing process steps and determination of economies of scale, SAMICS can assess the effects of changes in

- Economic conditions (interest rates, inflation rates, prices),
- Government policies (tax credits, depreciation formulas, industry structure),
- Company management (fiscal structure, required rate of return on equity).

A second major limitation is that all factories in the industry are assumed to operate in a production-line mode. SAMICS does not include cost elements to account for set-up costs or for sequencing bottleneck costs, such as must be considered in job shops and flow shops. Nor does SAMICS consider the use of specific work stations for the production of a variety of products. (SAMICS companies, however, can produce a range of products.) The SAMICS data base contains an assumption that every factory operates around the clock for 345 days per year. The changes required to permit user specification of the number of shifts, the number of operating days per year, and so on, are minor and are currently being implemented.

The SAMICS factories are sized by the input annual production quantity, the fractions of capacity at which the plants operate, and the detailed process descriptions. The costs of allowing room for expansion can thus be identified. SAMICS can compare the costs of factories of different sizes and the same production level or of the same size and different production levels, but these cost differences are not the incremental costs of growth: SAMICS assumes that each factory was built from scratch. The fact that the SAMICS factories do not grow does not preclude the industry from growing; additional factories with the same or different technology can enter the industry. (These new factories may change

the market price, but they cannot change the prices the modeled factories have to be able to charge to cover costs and make the specified profit.)

The operating costs (and revenues) of real companies vary widely from year to year, especially in the first few years of operation. In order to calculate a unique annual cost rate, SAMICS assumes that the modeled factories have reached a steady-state operating condition, but that they are still paying off the expenses of getting started. The eventual factory shut-down is assumed to be so far in the future that its effects on costs are negligible. The resultant smoothing of annual costs does take into account escalation rates and each company's discount rate.

Learning curve phenomena can be easily investigated, but only by explicitly assuming which parameters of which process descriptions change, and by how much.

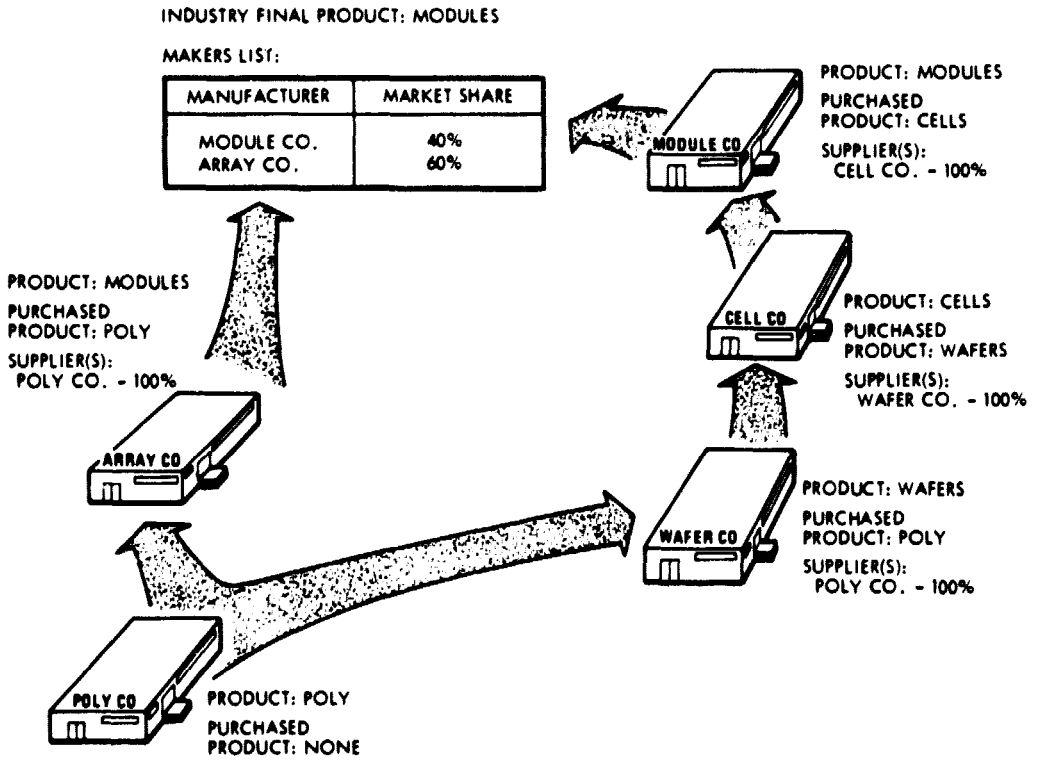

Figure 3. A Possible Structure of the SAMICS Industry. The companies that make the industry's final product, and their shares of the market are specified on a "Makers List." Each product required by a company has a "Suppliers List." (In SAMICS terminology, a "product" is something made within the modeled industry. Products not made within the industry are called "commodities," and their prices are input, rather than calculated.) In this illustration, SAMCO is more vertically integrated than MODCO; although they both make modules, SAMCO's input product is closer to the raw materials end of the industry.

Overview of the SAMICS Methodology

In concept, the SAMICS methodology is quite simple. Complications come in only in the detailed submodels that are internal to the model (such as in the calculation of corporate income taxes).

The structure of the industry is defined by specifying who (which of the hypothetical companies) buys what from whom, as illustrated in Figure 3. Each hypothetical company is defined by listing the manufacturing processes it contains and by specifying values for a variety of financial parameters. Except for the process lists, these inputs are standardized. The company description is illustrated in Figure 4.

Each manufacturing process (see Figure 5) is defined in terms of a few performance and cost parameters and a detailed list of its direct requirements. (Direct requirements are those things required by the process to produce its product, such as factory floor space, assembly line workers, electricity, cooling water, sulfuric acid, and silicon wafers.)

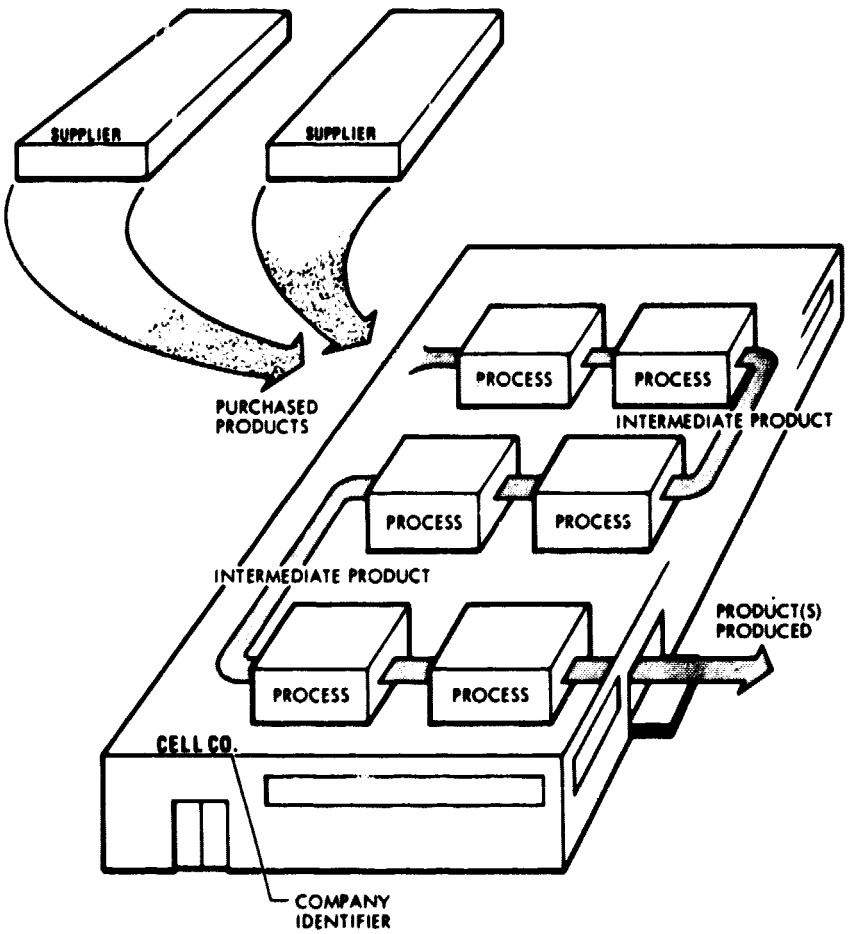

Figure 4. The SAMICS Company Description. Non-standardized input consists of company identifiers (a short referent and a longer descriptive name), a list of products produced, a list of processes used, and a list of purchased products. Each purchased product has a list of suppliers. Not shown in this figure is the collection of standardized financial parameters.

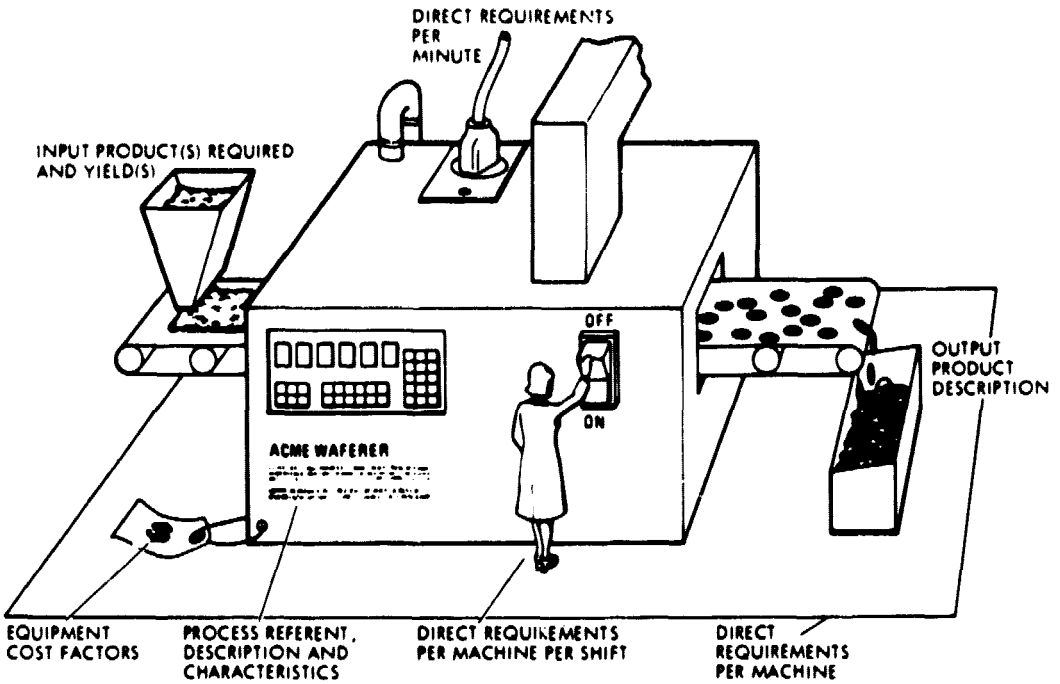

Figure 5. The SAMICS Manufacturing Process Description. The core of the input to the SAMICS methodology is the description of manufacturing processes. The number of machines is determined from the annual output quantity and the process characteristics (output rate and machine duty cycle). The process sequence is determined from the input/output product specifications. Direct requirements are determined from the direct requirements of the process, the number of machines, and standardized operating times. Indirect requirements (foremen, air conditioning, parking lot, etc.) are determined by the SAMICS methodology to be those needed to support (after aggregation to the company's scale of operation) the direct requirements.

An extensive body of standardized data is a part of SAMICS. This standard data includes indirect requirements relationships (such as how much building space is needed for each square meter of factory floor space), price information for all direct and indirect requirements, capital cost estimating relationships for each of the facilities parameters, and economic parameters (such as the general rate of inflation and the corporate income tax rate schedule). The casual user of SAMICS need not concern himself with any of this standard data.

Once the descriptive data is ready, the user specifies the annual production quantity of the industry, and the SAMICS methodology is applied [either by hand or by using the SAMIS III computer program (References 7, 10, 11)] as illustrated by Figures 6, 7, and 8.

First, all product and direct requirement quantities are calculated from the annual quantity of the industry by using the industry structure and the process descriptions. Within each company, direct requirements are collected and used to infer the indirect requirements.

Then, starting at the raw materials end of the industry, so that product prices are always known when needed, all of the annual expenses of each hypothetical company are calculated in turn, using standardized prices. Overhead expenses are calculated explicitly

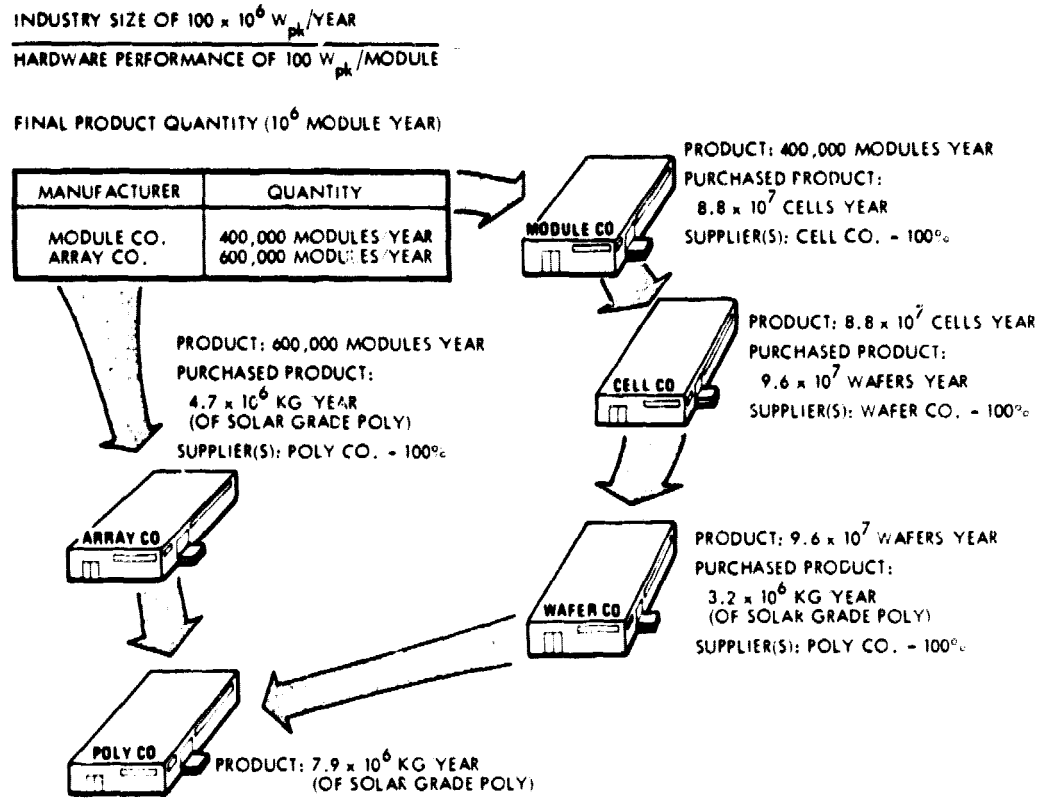

Figure 6. The SAMICS Methodology Quantities Calculation. The assumed annual industry demand generates "orders" for each company's output product(s). The purchased product quantities are determined by generating similar "orders" for each process step in each company's process sequence, using manufacturing process yields. After all quantities have been calculated, prices of all intra-industry products are calculated, starting at the raw materials end of the industry, as illustrated by Figure 7.

from the indirect requirements. Remaining company expenses (such as replacement of facilities, income taxes, profit, and partial recovery of start-up expenses) are calculated from a financial model of the firm. To facilitate detailed study, all expenses are allocated back to the processes. Finally, product prices are calculated by equating annual revenues to annual expenses. Eventually, the price of the final product of the industry is obtained.

Input Data Requirements

For use in the solar array industry, SAMICS specifies all of the input data required except the company process lists and the detailed process descriptions. It should be noted, however, that SAMICS is still evolving, as is the technology with which it is intended to deal. Hence, frequent minor additions to the standard data base are to be expected.

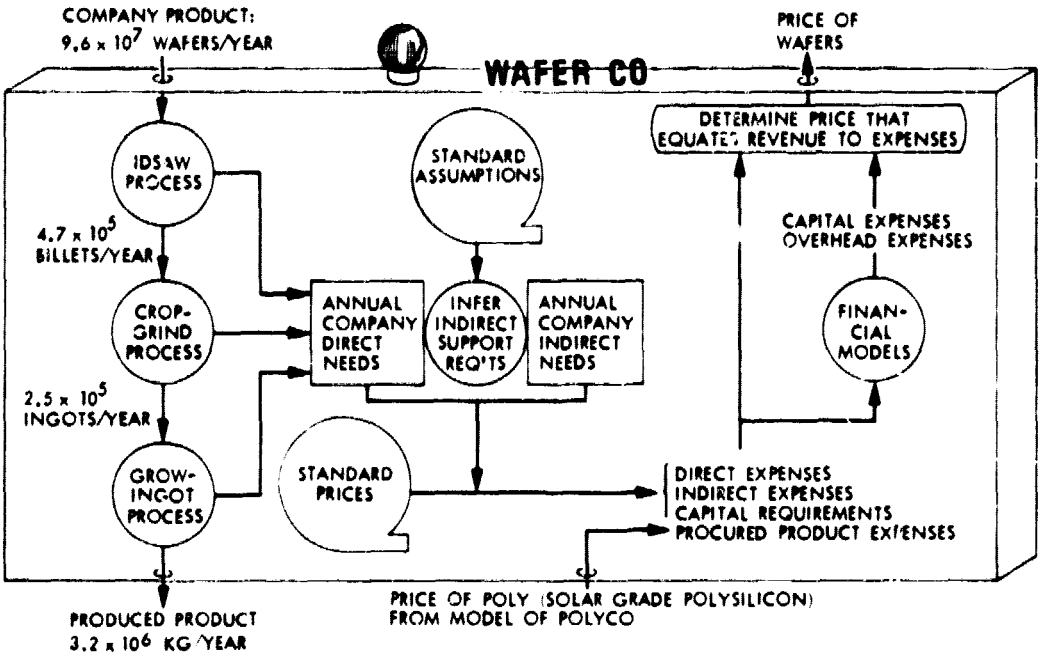

Figure 7. The SAMICS Methodology Price Calculation. During the calculation of product quantities (Figure 6 and the left side of this figure), annual direct needs are accumulated within each company. Standard assumptions are used to infer company indirect requirements. Financial models provide estimates of overhead expenses, then the company's product price is chosen so that annual revenues equal annual expenses. (Profit is considered to be one of the expenses that must be covered by revenue). This price is then passed along to the company that purchases this company's product.

Process Description.

It will generally be the case that the most difficult, time-consuming activity in the application of SAMICS will be the development of an initial set of process descriptions. A detailed understanding of the direct requirements of each of the processes in the hypothetical companies is essential for the preparation of any detailed cost estimate.

Application Beyond the Solar Array Industry

In order to apply the SAMICS methodology to other industries, it is necessary to replace the standard industry structure data with data which is appropriate. It is also necessary to develop the relevant process descriptions. These are straightforward procedures.

A more difficult requirement is the need to augment the standardized data base. Price information must be obtained for any new kinds of direct or indirect requirements. Capital cost estimating relationships are needed for any new kinds of facilities parameters. And, indirect requirements relationships must be developed for every new kind of direct and indirect requirement. None of these is particularly difficult to do, but the character of the analyses required is different from that of the other data preparation tasks.

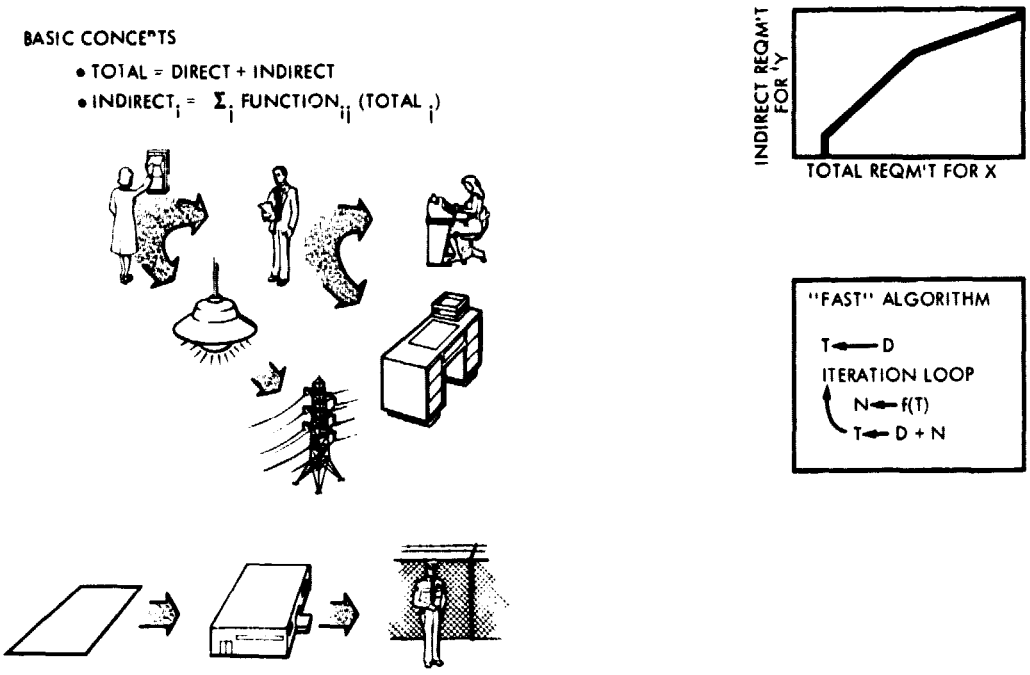

Figure 8. The SAMICS Methodology Indirect Requirements Inference. Direct requirements, such as the *laborers* and *floor space* shown at the left, must be supported in order to run a company. The laborers require supervisors and plant lighting (to mention just two of their needs). The supervisors, in turn, require secretarial support and office equipment; the lighting requires electricity; and so on. Floor space requires walls and ceilings. The facilities require guards and fences. These indirect requirement relationships are defined numerically by standardized functions, as suggested in the upper right of this figure. A fast algorithm for calculating the indirect requirements resulting from the direct requirements has been developed, and is hinted at in the box at the lower right.

Validation Activities

Ensuring that the SAMICS methodology produces believable price estimates and cost breakdowns has been a major consideration throughout its three years of development (Figure 9).

There are three major components to the validation plan. The first is an ongoing solicitation of criticism, both constructive and otherwise. The methodology has been presented in detail within the Jet Propulsion Laboratory, at Low-Cost Solar Array Project Integration Meetings, at DOE Photovoltaics Program semiannual reviews, at IEEE Photovoltaics Specialists Conferences, and at a joint meeting of the Operations Research Society of America (ORSA) and the Institute of Management Sciences (TIMS). Individual LSA project contractors have been asked to comment on the methodology. A management consulting firm was even hired to prepare a detailed critique (Reference 4).

The second major part of the validation plan is the comparison of SAMICS results with the results of a detailed conceptual plant design produced by conventional methods. This comparison is underway — conceptual plant designs for a specified process sequence at three scales of operation were obtained from a contract in the summer of 1977 (Reference

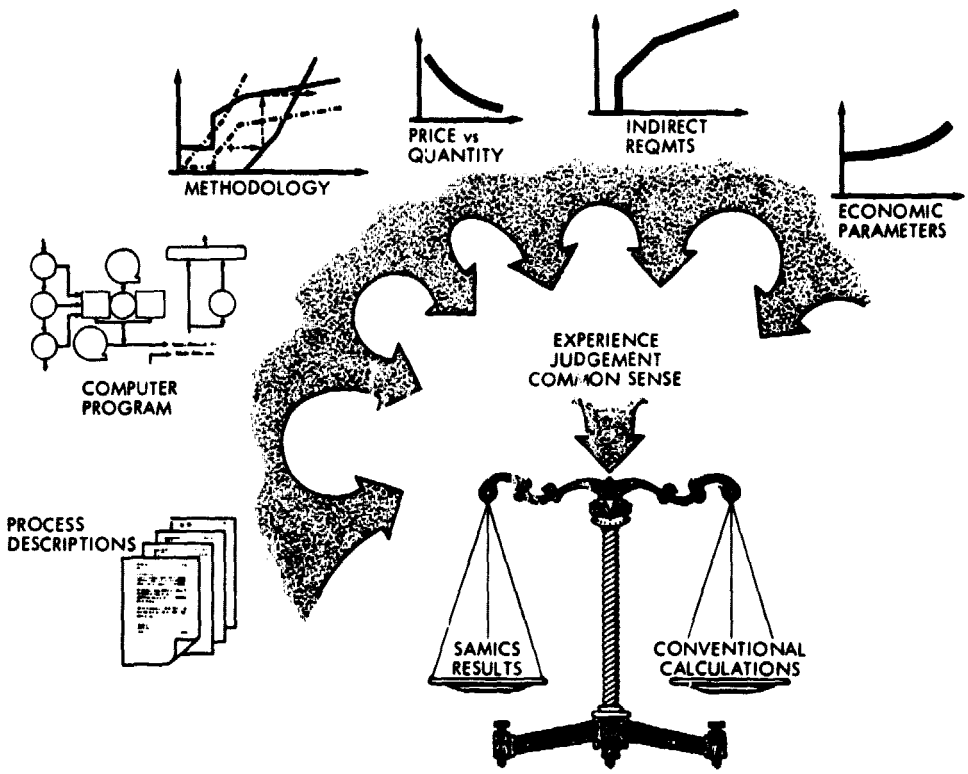

Figure 9. Validation of SAMICS. Intensive and extensive attention has been given to assuring the validity of SAMICS in all four of the following areas: Standardized data (economic parameters, indirect requirements relationships, and price versus quantity functions); standardized methodology, including the SAMIS III computer program; nonstandardized data — the process descriptions; and, most important of all, the reasonableness of results.

5, Volume III): the SAMICS methodology is being applied to the same sequence at the same scales of operation during the latter part of 1978.

The third major part of the validation plan is the continual application of common sense and experienced judgment by users of the methodology. This is expected to be especially valuable in finding and correcting flaws in the standardized price data.

In addition to the major steps described above, the validation plan includes close attention to many more minor details. For example, despite the novelty of many of the SAMICS submodels and algorithms, much of the extensive cost estimation literature has been reviewed, assessed, and incorporated. The approach chosen minimizes the use of judgmental factors and "undetermined coefficients" in order to maximize the testability of the methodology. Modern programming methods — such as use of a design language, structured design, and "egoless programming" — were employed to ensure correctness of the computer program. The complete methodology was simplified to produce a manual procedure, which was then applied to a complete process sequence. The resulting price estimates and cost breakdowns were then assessed for validity. These manual results have been compared in detail with the computer results for the same process sequence.

Much, but not all, of the validation plan has been completed. Release of the methodology and the computer program before validation is complete does entail some risk. This risk is unavoidable, however, because part of the validation process requires application by as wide a variety of users as possible. Deferring application until no risk remains would result in unacceptable delays in implementation.

Obtaining a SAMICS Capability

Full instructions for applying the manual SAMICS procedures are contained in References 2, 3, 5 (Volume I), 12, and 13.

The computerized version of the SAMICS methodology can be obtained in either of two forms. Virtually immediate access can be achieved by establishing an account with NCSS, Inc. (a nationwide time-sharing service — call (213) 277-7511 collect, ask for Ms. Susanna Chen, and mention the SAMIS III computer program) then obtaining detailed instructions for SAMIS III operation from Mr. Paul J. Firnett of JPL (call (213) 354-4670). Mr. Firnett will also send you a copy of the SAMIS User's Guide (Reference 10).

The SAMIS III computer program is intended to be portable to any machine with a Simscript II.5 compiler. A tape copy of the source code can also be obtained from Mr. Firnett. Those who wish to establish the program on their own computer system will also want to obtain copies of References 7 and 11.

Eventually, the SAMIS III will be available from COSMIC (the Computer Software Management and Information Center, Suite 112, Barrow Hall, University of Georgia, Athens, Georgia 30602, (404) 542-3265), which was established to disseminate computer software developed by governmental agencies to other governmental agencies, to industry, and to educational and research institutions.

SAMICS Documentation

The SAMICS methodology is fully described by the documentation listed in this section. Copies may be obtained from the

LSA Data Center
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91103
(213) 354-4321

Since SAMICS is still under development, there is an active mailing list for those interested in updates. To be added to that distribution list, please write Mr. Robert G. Chamberlain at the same address.

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*JPL internal document.